PROBLEM SET #3

Issued: Tuesday, Sep. 25, 2012

Due (at 7 p.m.): Tuesday Oct. 4, 2012, in the EE C245 HW box near 125 Cory.

1. The following pages comprise a surface micromachining process flow for a second-order clamped-clamped beam micro-mechanical filter. 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.).

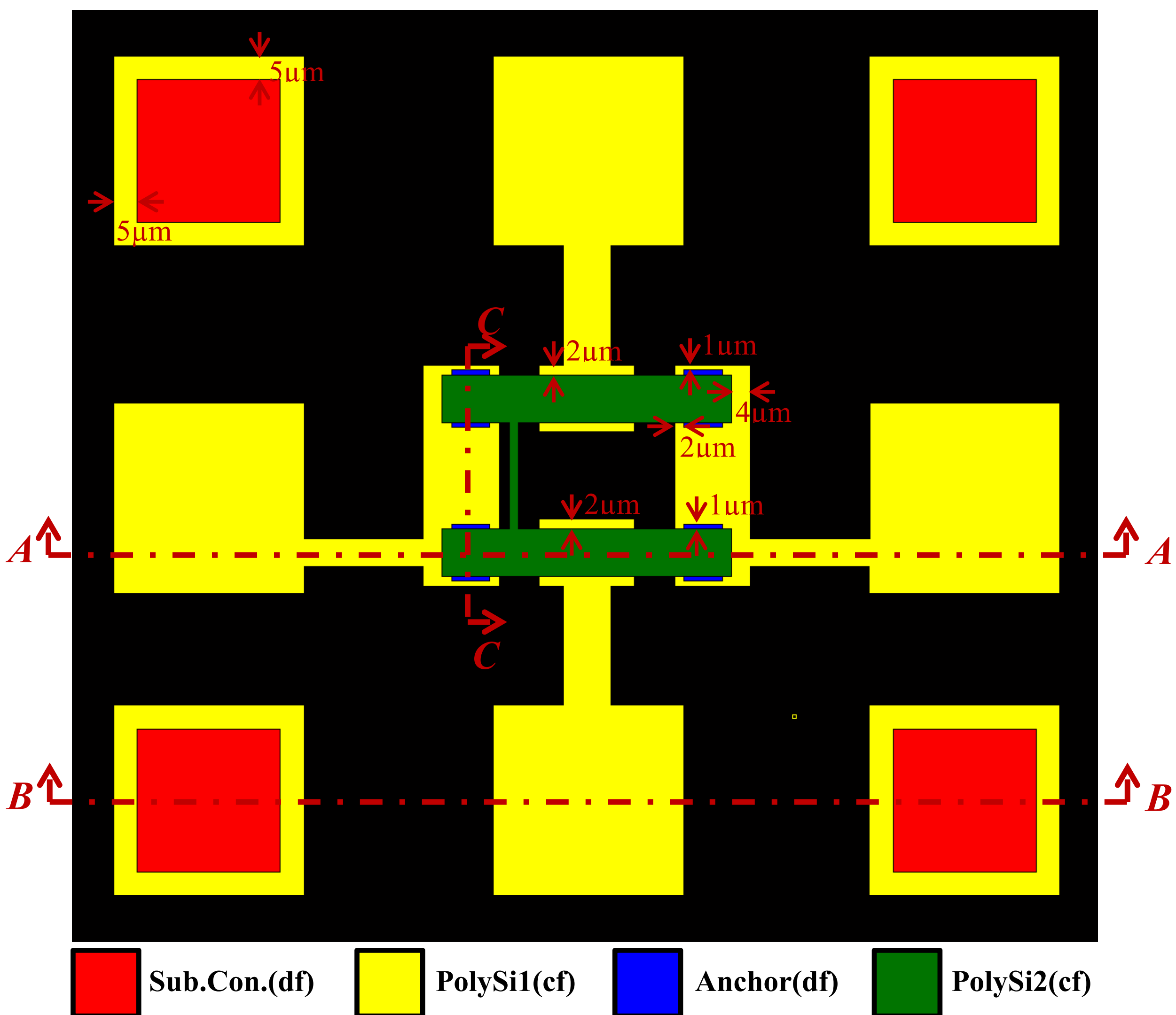
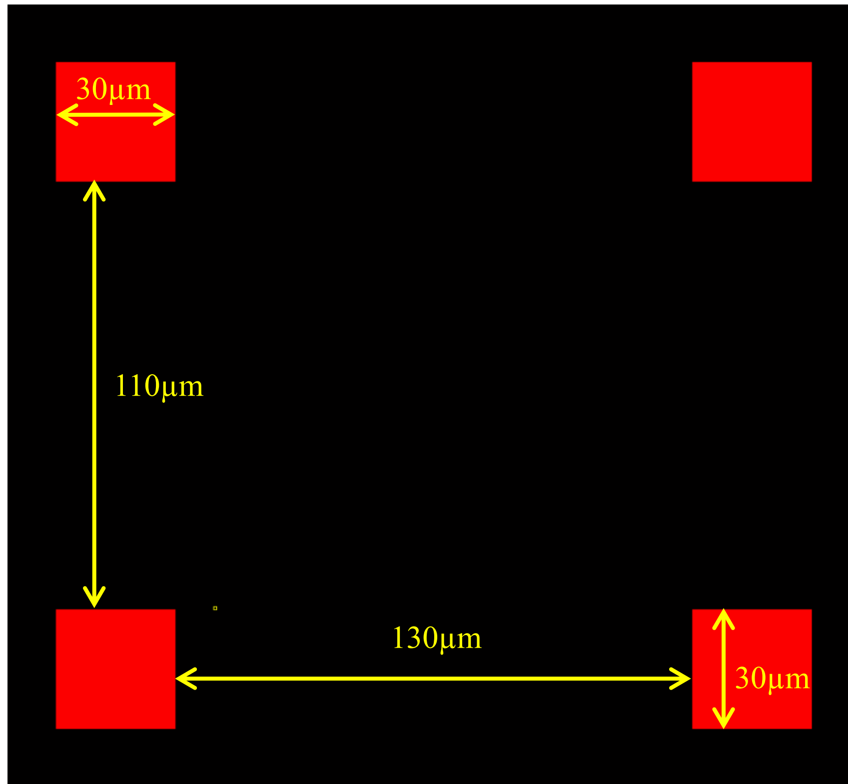
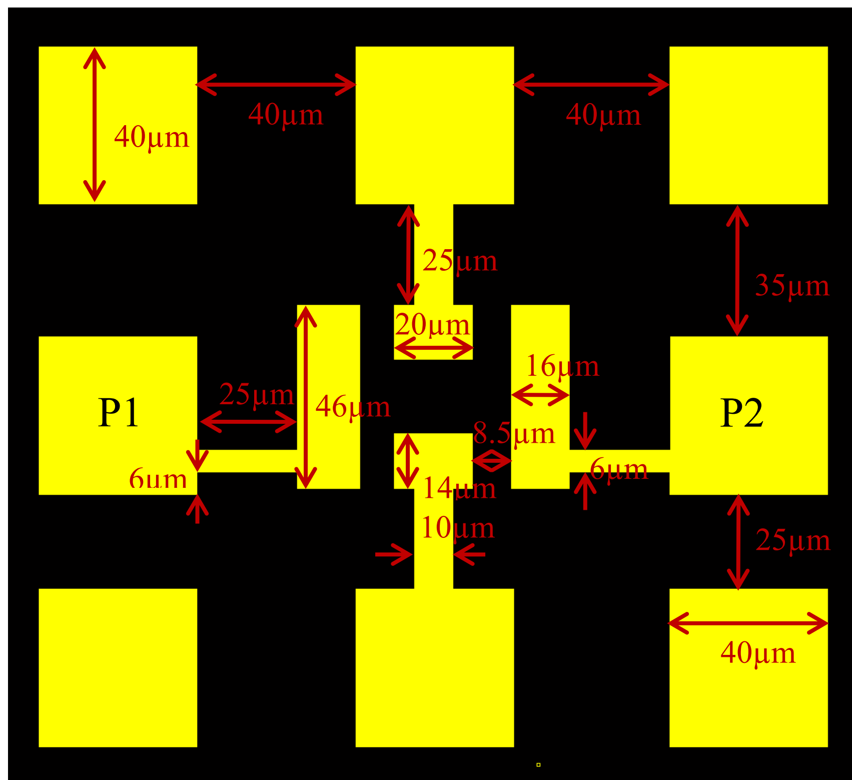


Figure PS3.1-1

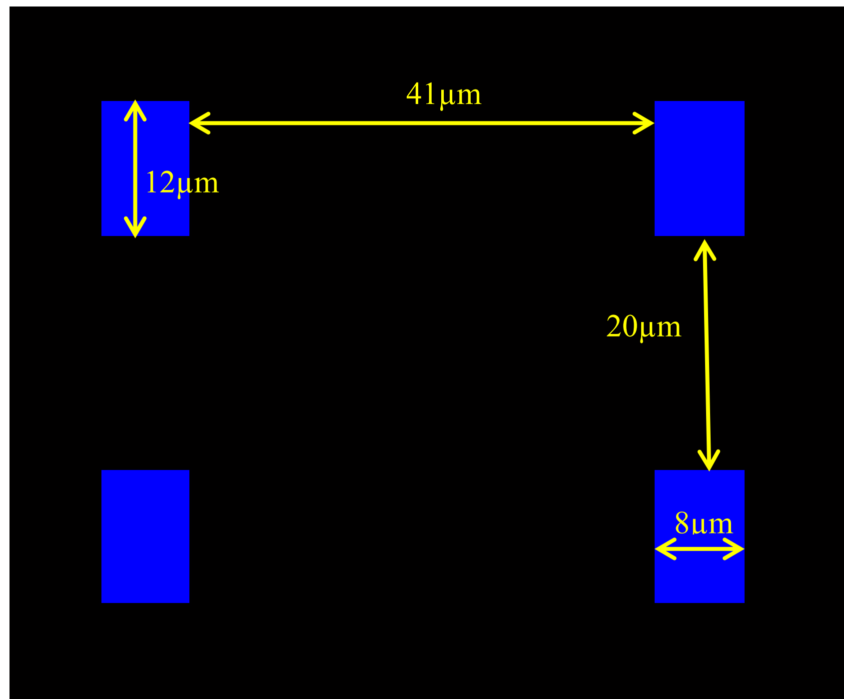
The four masks used in this process flow are shown below with dimensions. The background color of the layout editor is black. This is "field" for all masks.



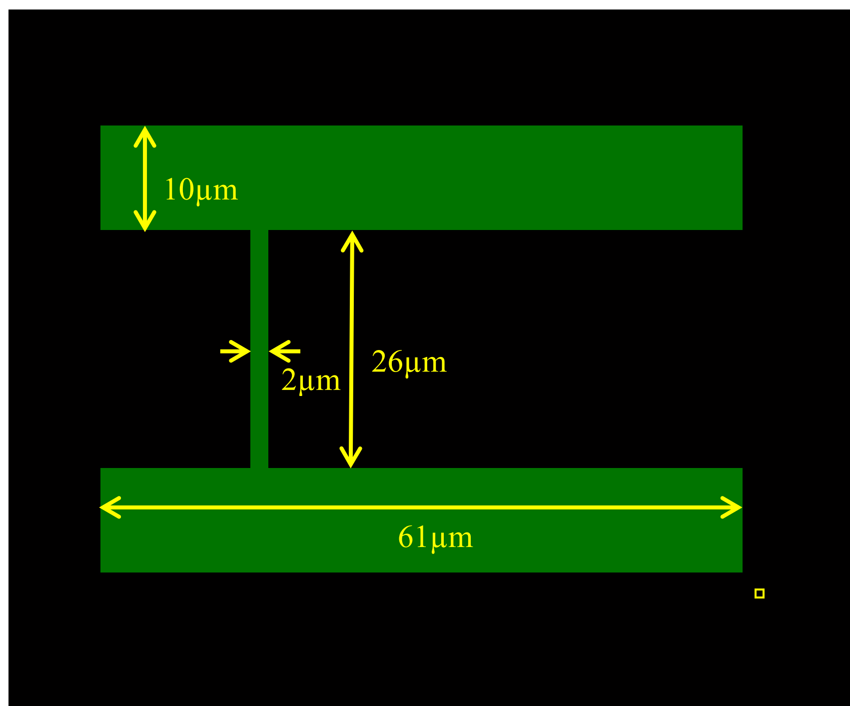
Mask 1: Sub.Con. (dark field)



Mask 2: PolySi1 (clear field)



Mask 3: Anchor (dark field)



Mask 4: PolySi2 (clear field)

Figure PS3.1-2

Lateral Clamped-Clamped Beam Micromechanical Filter 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)

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 A 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 = 400 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 = 500 nm
Phosphorus-doped polysilicon deposition:
Tystar16, 16VDPLYA
time = 2 hour 30 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 Lam5 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 = 100 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

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 lam2:
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 lam2.

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

13.4 Etch 2nd poly in lam5:
(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 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.

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 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) at the end 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) Conformal deposition on the wafer when there is topography on the surface can lead to stringers. Why should a process designer be aware of potential stringers and avoid them? Point out the possible stringers in this process and propose a solution to remove them with minimal impact to the intended structure.

(c) Assume the sheet resistance of the interconnect polysilicon (i.e., PolySi1) is 20 Ω/□, and that of the polysilicon structural material (i.e., PolySi2) is 5 Ω/□. Calculate the total resistance between the centers of bond pads P1 and P2 (where probe tips might be placed in contact).

(d) Suppose each 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 each beam. Suppose also that if a beam bends, the sacrificial gap varies according to the following shape function:

$$g(x, C) = g_0 - Cu_1(x); \text{ for } 0 \le x \le L \text{ and } 0 \le C \le g_0$$

where C is the downward displacement of the beam towards the substrate at its midpoint, L is the length of the beam, g_o is the initial gap spacing of the unperturbed beam, and $u_1(x)$ is the first solution of displacement function you derived in HW#1

$$u_1(x) = -0.629\left[\cos\left(4.73\frac{x}{L}\right) - \cosh\left(4.73\frac{x}{L}\right)\right] + 0.618\left[\sin\left(4.73\frac{x}{L}\right) - \sinh\left(4.73\frac{x}{L}\right)\right]$$

If the contact angle of water between the underside of a beam and the substrate (and underlying electrode) is $\theta_c = 30°$, and the room-temperature surface tension of the water-air interface is $\gamma_{la} = 72.75 \times 10^{-3}\,N/m$, will the device be stuck down after drying in air? Consider only stiction forces under the 41μm section (what we'll call the active area) between the anchors of each beam, and lump all the stiction force over the active area into a single force at the midpoint of each beam.

(e) Assuming the same *g(x)* function as in 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?

(f) Now suppose a step-function voltage V_{in} is suddenly applied between bond pads *P1* and *P2*. With what time constant will each beam reach its steady-state temperature after the step voltage is applied?

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 130 W/m.K.

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

2. You are given a wafer with the cross-section shown in Figure PS3.2-1 and *intend* to pattern and release the structure to leave only the polysilicon structure atop the blanket nitride/oxide layer as shown in Figure PS3.2-2. To perform the release, you first dry etch the polysilicon in an RIE system with etch rate and selectivity given in Table 2.5-1. You then wet etch the oxide layer in a completely isotropic etchant with characteristics given in Table 2.5-2. (Note that you intend to achieve the structure of Figure PS3.2-2, but whether or not you actually can depends on the process.)

Since the deposition steps are not completely uniform, the layer thickness may not be the same over the entire wafer. So when you are etching a layer, you need to etch a bit longer than what you calculate from knowledge of thickness and etch rate to make sure all structures are etched completely. It is common practice to etch for 20% longer than the calculated time (i.e., do a 20% overetch). Include this overetch in your calculations for this problem.

(a) How long should you etch the polysilicon layer based on the nominal thickness of the layer and 20% overetch? Draw the wafer cross-section immediately after the polysilicon etch step. You can assume the RIE etch is completely anisotropic.

(b) How long does it take to completely release the structure? Draw the wafer cross-section immediately after the release step. Assume the wet etch is completely isotropic.

(c) As you have seen, there are two major problems with this process. Explain what caused these problems and how one might fix them. Draw the final cross-section attained by your proposed fixes.

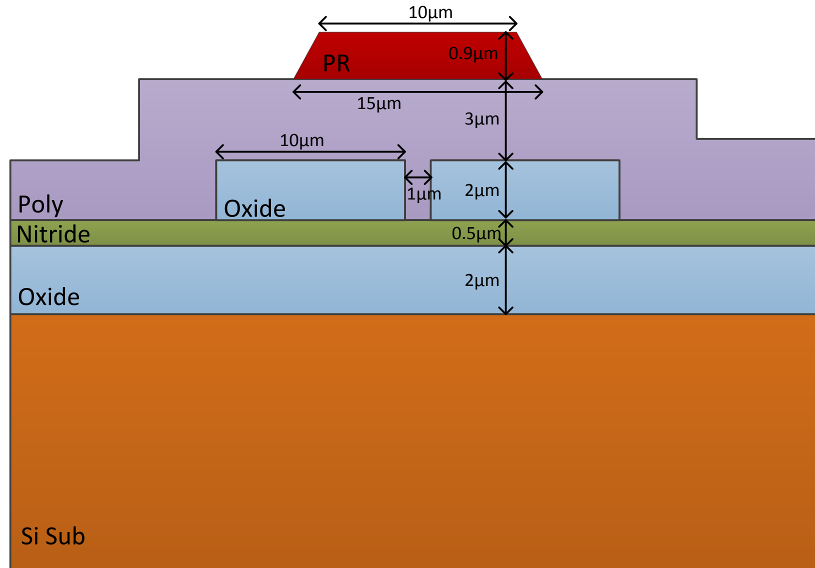

Figure PS3.2-1

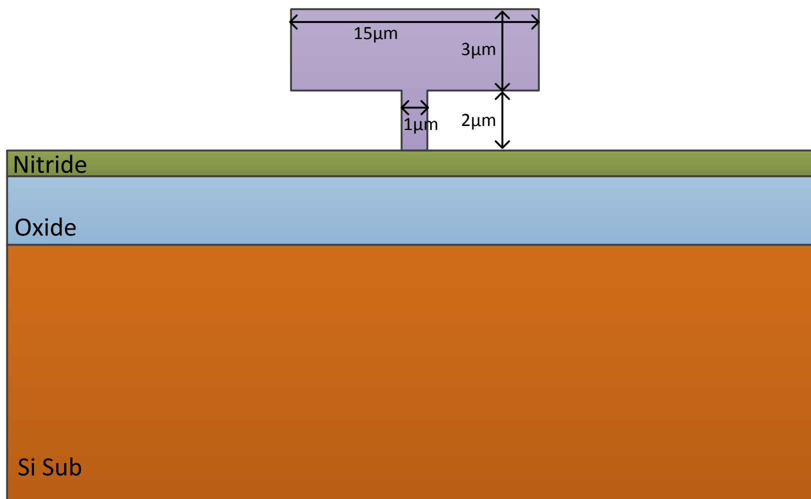

Figure PS3.2-2

Table 3.2-1

Polysilicon etch rate	0.5µm/min
Selectivity over Oxide	5:1
Selectivity over Nitride	10:1
Selectivity over Photoresist	2:1

Table 3.2-2

Oxide etch rate	0.2µm/min
Selectivity over Poly	10:1
Selectivity over Nitride	5:1
Selectivity over Photoresist	5:1