PROBLEM SET #3

Issued: Saturday, February 20, 2016

Due: Wednesday, March 2, 2016, 8:00 a.m. in the EE C247B homework box near 125 Cory.

1. The following pages comprise a surface micromachining process flow for a clamped-clamped micromechanical beam with 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 Berkeley Marvell 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. temperatures, times, doses etc.

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 perfectly flat upper surface.

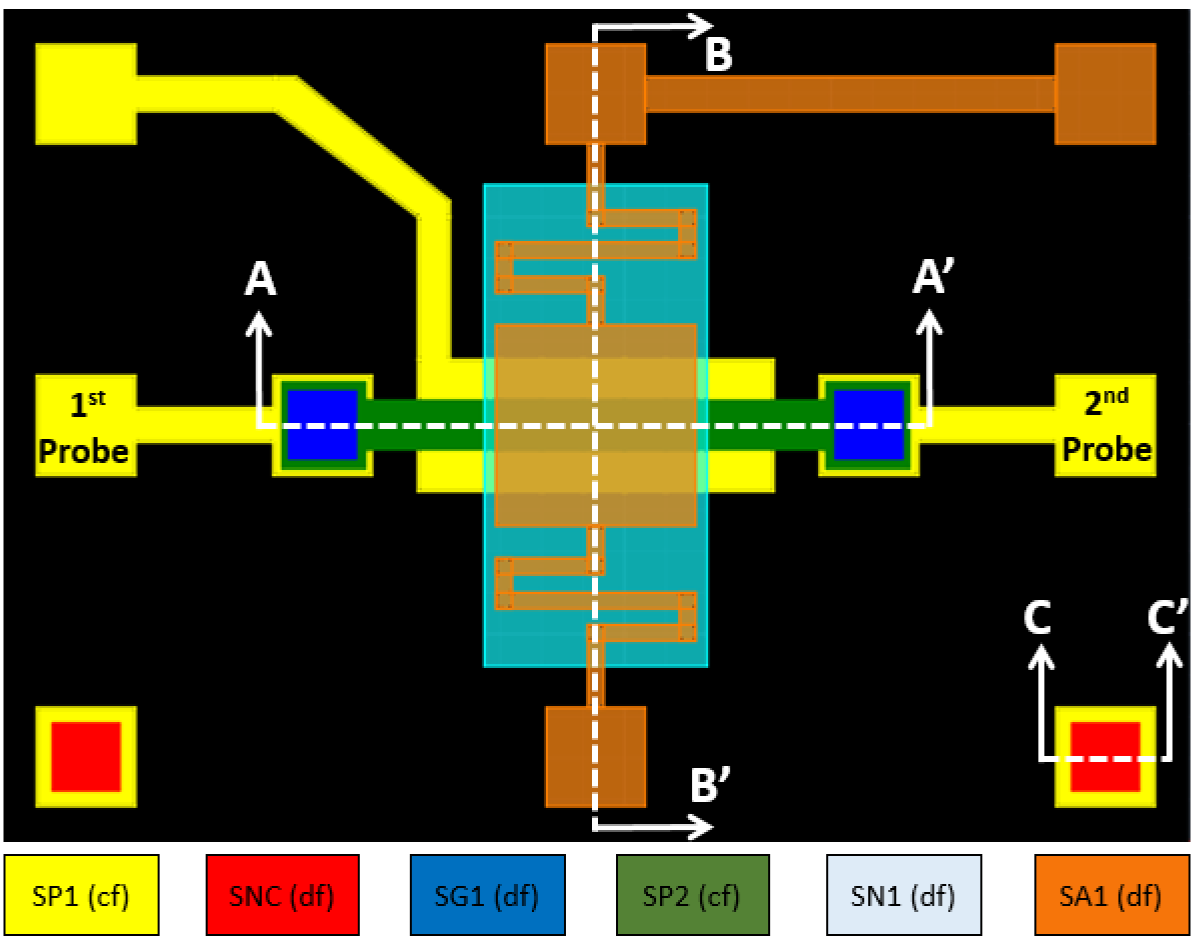

Fig. PS3.1

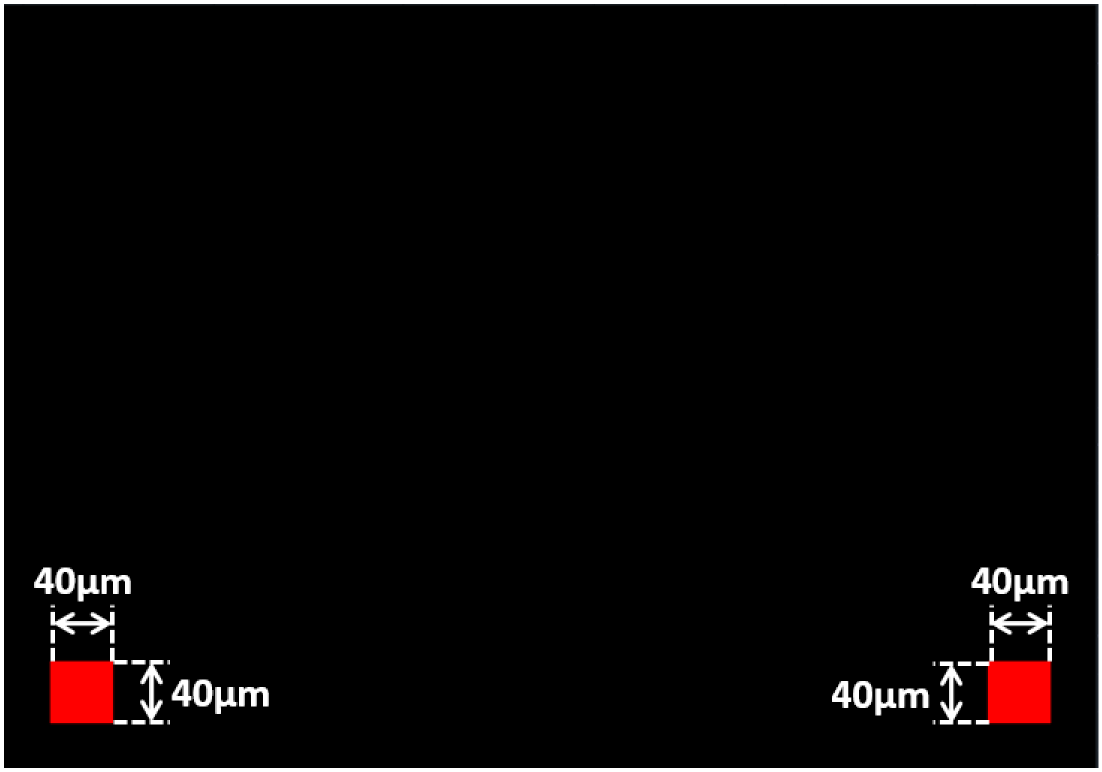

Fig. PS3.2

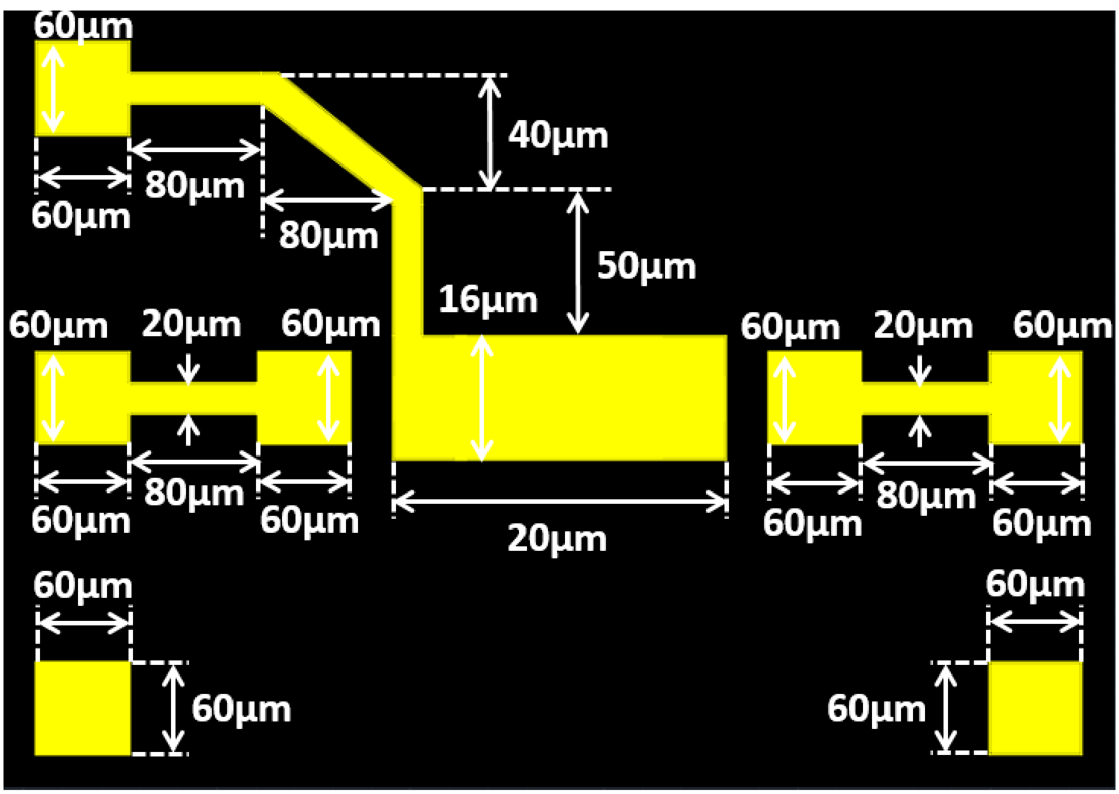

Fig. PS3.3

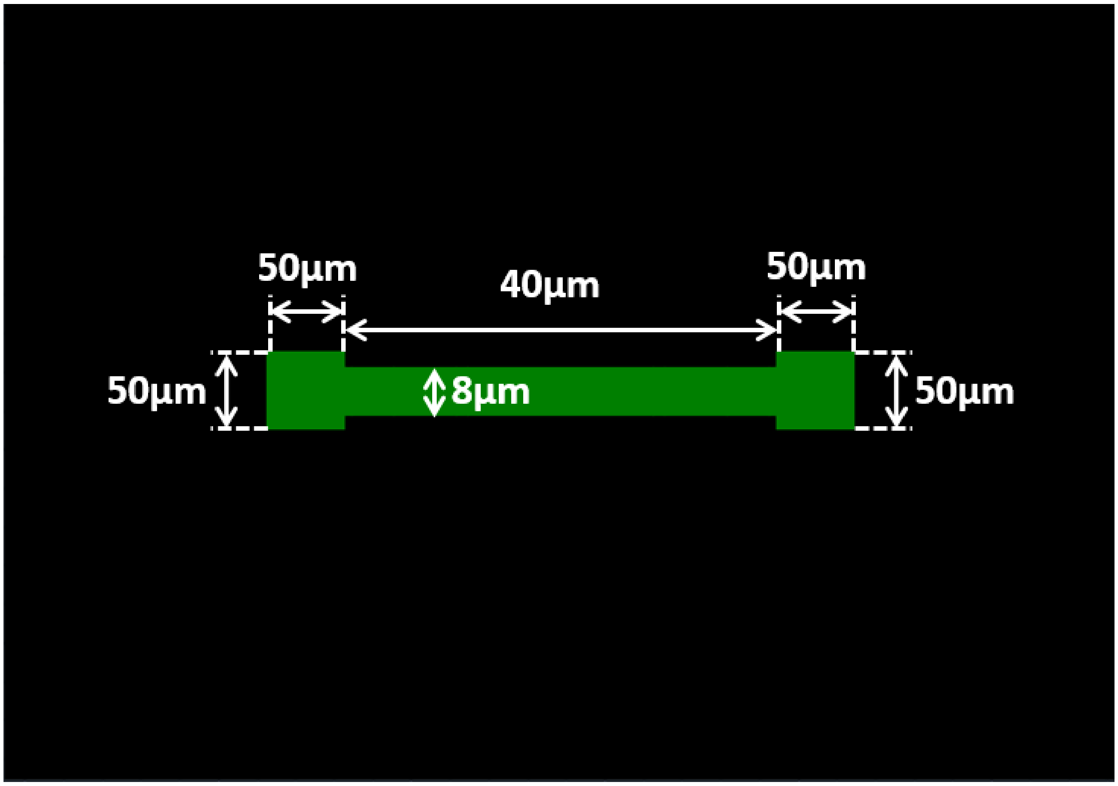

Fig. PS3.4

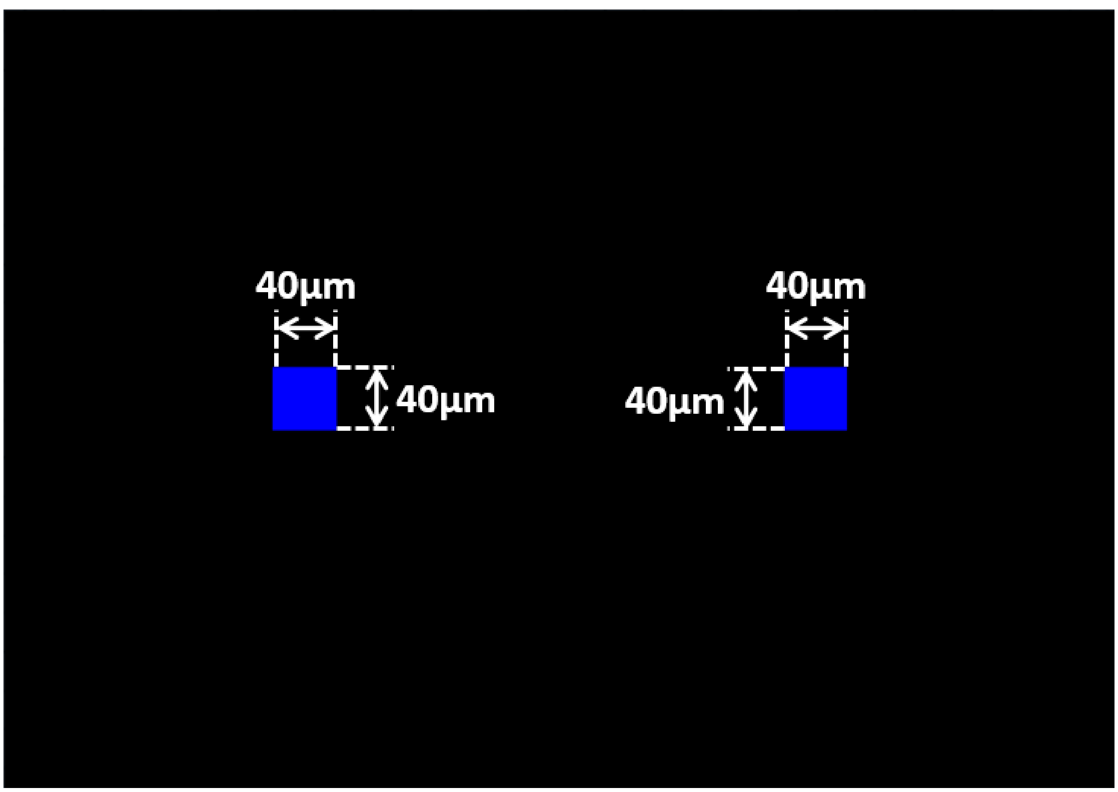

Fig. PS3.5

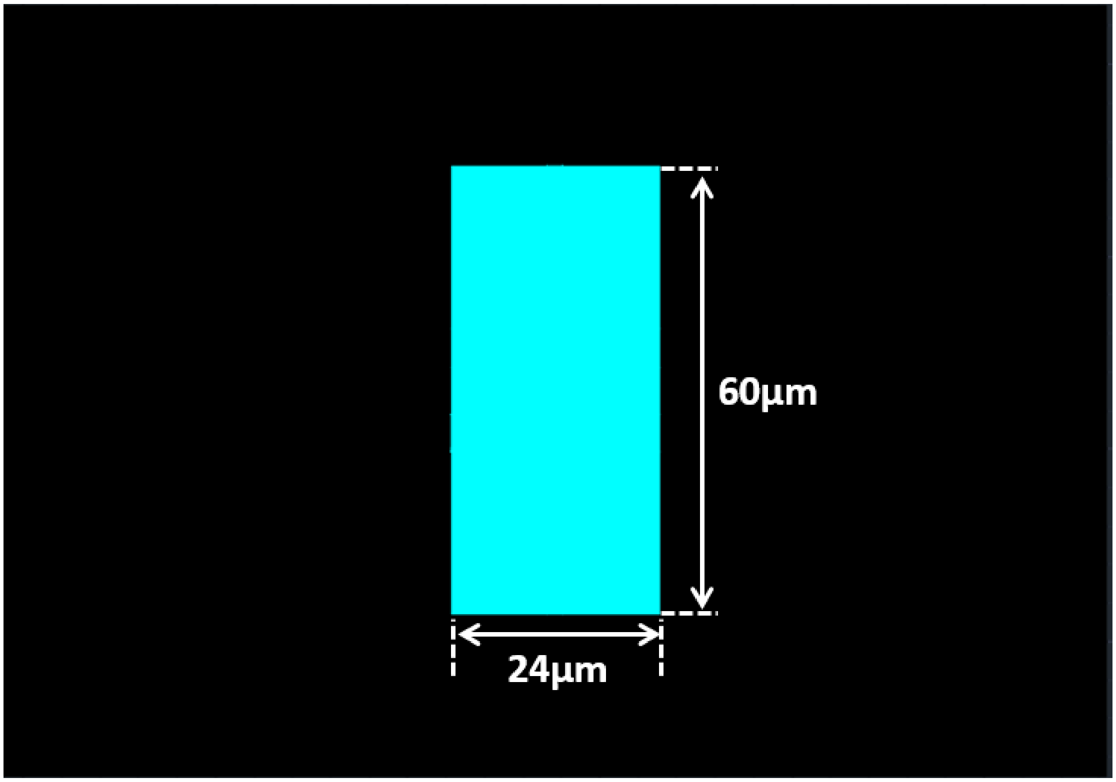

Fig. PS3.6

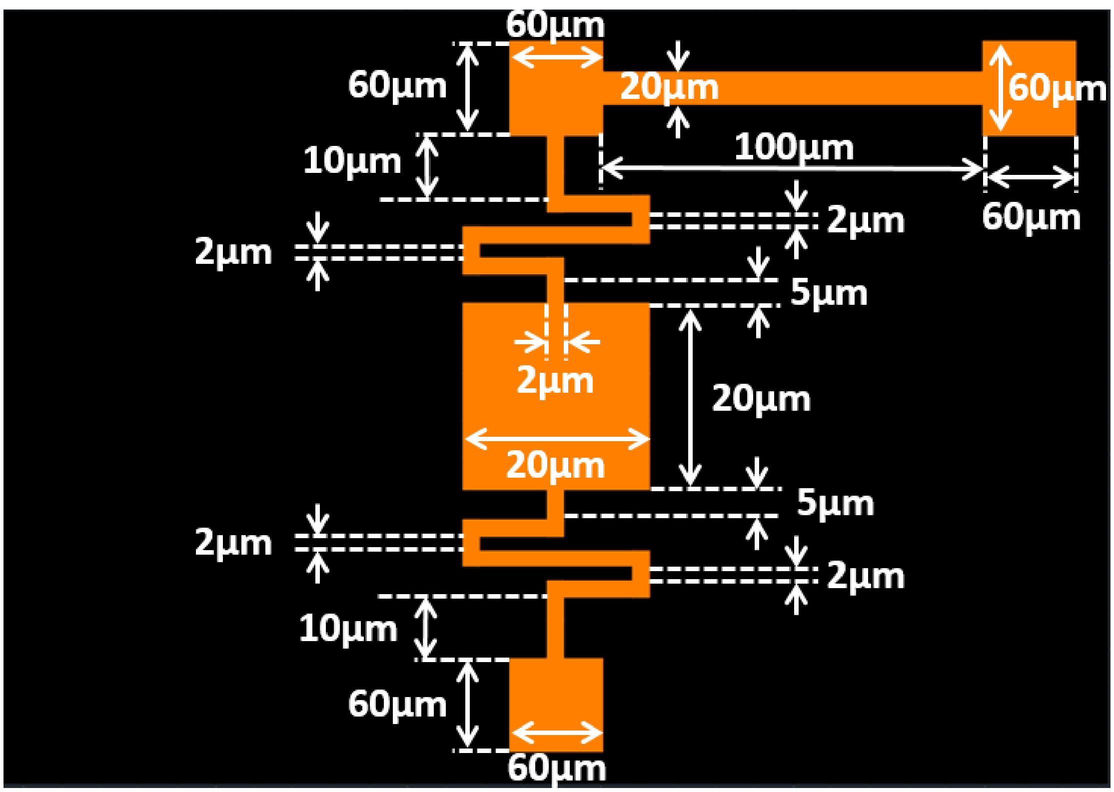

Fig. PS3.7

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	$S_{A/B}$
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
		Gold	500:1
HF (Release)	Oxide	Stoichiometric	250:1

Table PS3.1

(a) Draw cross-sections of the structure along the A-A', B-B', and C-C' lines in the layout:

i. after step 14.2 of the process.

ii. at the end of the process.

Here, the thickness dimensions should be correct to within 100nm or 20%, whichever is finer. Draw the length (horizontal) dimensions using a compressed scale. If any structures completely detach from the wafer, 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) Assume the sheet resistance of the interconnect polysilicon (POLY1) is $20\Omega/\square$, and that of the polysilicon structural material (POLY2) is $5\Omega/\square$. Calculate the total resistance between centers of the bond pads (where a probe tip might be placed in contact) for the leads that attach to the ends of the beam, i.e. calculate the resistance between the 1st and 2nd probes in Fig. PS3.1.

(e) Suppose the beam structure has an effective restoring stiffness at its midpoint of 1500N/m, and for argument's sake, suppose that you can use this number to represent the total restoring stiffness of the beam. (In actuality, as we'll see later, the stiffness of the beam is a function of location on the beam, so the influence of stiction forces must actually be integrated over the beam length. We, however, will ignore this for now, and return to it in a later problem set.) If the contact angle of water between the underside of the beam and its underlying electrode is 30°, and the room temperature surface tension of water-air interface is $72.75x10^{-3}$N/m, will the polysilicon clamped-clamped beam be stuck down after drying in air?

(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?

Clamped-Clamped Beam μMechanical Resonator with Top Metal Electrode Process

0.0 Starting Wafers: 8-12 Ω-cm, n-type, (100) prime or just n-type test wafers.
Control Wafers: PSGIF, PSGIB (Si)
NITIF, NITIB (Si)
POLY1F, POLY1B (tylan11 ctrl)
PSG2F, PSG2B (Si)
POLY2F, POLY2B (Si)
PSG3F, PSG33 (81)

1.0 $POCl_3$ 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 PSG1 Deposition: target = 2μm
(immediately after n+ diffusion)
Tystar12, recipe 12VDLTOA
Flows (sccm): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
Time (2μm) = 1hr 40min (1000A per 5min)
Include etching controls: PSG1F and PSG1B

3.0 Nitride Deposition: target = 300nm
Deposit stoichiometric nitride:
Tystar17, recipe STDNITA.017
Temp. = 800°C, Flows (sccm): SiH_2C_{12} = 25, NH_3 = 75
Time = 1hr 22min (220nm per hour)
Include etching controls: NIT1F and NIT1B

4.0 Substrate Contact Mask: SNC (chrome-df)

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

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

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

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

4.5 Remove resist, piranha clean wafers.

5.0 μStructure Poly1 Deposition: target = 300nm
Phosphorous-doped polysilicon deposition:
Tystar16, recipe 16VDPLYA
Time = 2hr 30min, Temp. = 650°C (~120nm per hour)
Include etching controls: POLY1F, POLY1B

6.0 μStructure Poly1 Definition Mask: SP1 (emulsion-cf)

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

6.2 Plasma etch polysilicon in Lam8 etcher, inspect
(Cl_2/HBr at 300W, 12 mTorr)

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

7.0 Sacrificial PSG Deposition: target = 200nm
Tystar12, recipe 12VDLTOA
Flows (sccm): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
Time (200nm) = 10min (1000A per 5min)
Include etching controls: PSG2F and PSG2B

8.0 Sacrificial PSG Densification
RTA in Heatpulse1: 30sec @ 950°C
(also do PSG2F and PSG2B controls)

9.0 (Optional) Dimple Photo Mask: CD1 (chrome-df)

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

9.2 Timed wet etch in 5:1 BHF.
(estimated etch rate ~300nm per min)

9.3 Remove resist, piranha clean wafers.

10.0 μStructure Anchor Photo Mask: SG1 (chrome-df)

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

10.2 Etch oxide in Lam6.
For 1μm oxide: etch as usual.
For 2μm oxide: [press. = 2.8Torr, power = 350W, gap = 0.38cm, CHF_3 = 30sccm, CF_4 = 90sccm, He = 120sccm, time = 1min], [power = 0, same gases, time = 1min] 3X
For both cases, overetch with 700W recipe.

10.3 Check contact using IV probe station.

10.4 Wet dip in 5:1 BHF for 10sec.

10.5 Remove resist, piranha clean wafers.

11.0 μStructure Poly2 Deposition: target = 2μm
Phosphorous-doped polysilicon deposition:
Tystar16, recipe 16SDPLYA
Time = 16hr 0min, Temp. = 650°C (~120nm per hour)
Include etching controls: POLY2F, POLY2B (tylan11 controls).

12.0 Oxide Mask Deposition: target = 500nm
Tystar12, recipe 12VDLTOA
Flows (sccm): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
Time (500nm) = 25min (1000A per 5min)
Include etching controls: PSG3F and PSG3B

13.0 RTA Anneal
Heatpulse1: 1min @ 1100°C

14.0 µStructure Poly2 Definition Mask: SP2 (emulsion-cf)
Align to µStructure Poly1.

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

14.2 Etch oxide mask in Lam6.

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

14.4 Etch Poly2 in Lam8: [press. = 280mTorr, power = 300W, gap = 1.5cm, CCl_4 = 130sccm, O_2 = 15sccm, time = 1min] then [power = 0, same gases, time = 1min] 5 or 6X, depending upon etch rate (etch rate usually 4000A per min).

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

15.0 Sacrificial PSG Deposition: target = 200nm
Tystar12, recipe 12VDLTOA
Flows (sccm): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
Time (200nm) = 10min (1000A per 5min)
Include etching controls: PSG2F and PSG2B

16.0 Sacrificial PSG Densification
RTA in Heatpulse1: 30sec @ 950°C
(also do PSG2F and PSG2B controls)

17.0 Nickel Seed Layer Definition

17.1 Ni Evaporate: target = 40nm
Edwardeb3, time (40nm) = 400sec (~0.1nm per sec)

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

17.3 O_2 Plasma etch PR in Ptherm etcher, inspect
Flows (sccm): O_2 = 100
Power = 150W
Time (8µm) = 8min (1µm/min)

17.4 Etch surface Ni with Ni etchant
$CH_3COOH:HNO_3:H_2SO_4$ = 5:5:2 solution
Time (40nm) = 2min (~20nm per 1min)

17.5 Remove resist:
Technics-c, 10min 02 plasma B 300W

18.0 Ni Spacer Definition Mask: SN1 (chrome-df)

18.1 Spin, expose, develop, inspect, descum, hard bake.
PR thickness: 5µm

18.2 Ni Electroplate:
Current = 3mA
Time (2.2µm) = 67min (~33nm per min)

18.3 Remove resist:
Technics-c, 10min 02 plasma B 300W

18.4 Remove Ni seed layer
$CH_3COOH:HNO_3:H_2SO_4$ = 5:5:2 solution
Time (40nm) = 2min (~20nm per 1min)

18.5 Remove PR.

19.0 Electroplating Seed Layer

19.1 Ni Evaporate: target = 40nm
Edwardeb3, time (40nm) = 400sec (~0.1nm per sec)

20.0 µStructure Au Definition Mask: SA1 (chrome-df)

20.1 Spin, expose, develop, inspect, descum, hard bake.
PR thickness: 5µm

20.2 Au Electroplate:
Current = 3mA
Time (2.5µm) = 100min (~25nm per min)

20.3 Remove resist:
Technics-c, 10min 02 plasma B 300W

20.4 Remove Ni spacer and seed layer
$CH_3COOH:HNO_3:H_2SO_4$ = 5:5:2 solution
Time (2.2µm) = 20min (~110nm per 1min)

21.0 µStructure Release

21.1 Piranha clean in sink8.

21.2 Wet etch in 5:1 BHF (~600nm 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 N_2 gun dry.

21.3 Piranha clean in sink8 for 10min. Follow with standard DI rinses. No HF dip. Spin dry or N_2 gun dry.
