Hw#8

[78 points]

1. [5 points]

A. [3 points] $\sigma_{max} = \frac{\pi^2 E a^2}{3L^2}$

$L = 200um\ and\ a = 1um$

$\sigma_{max} = 82u * E$

E is a variable since it's a "new" material.

Compressive because the beams buckle. Tensile films don't buckle because once released, they contract. Buckling is caused by clamped-clamped beams lengthening.

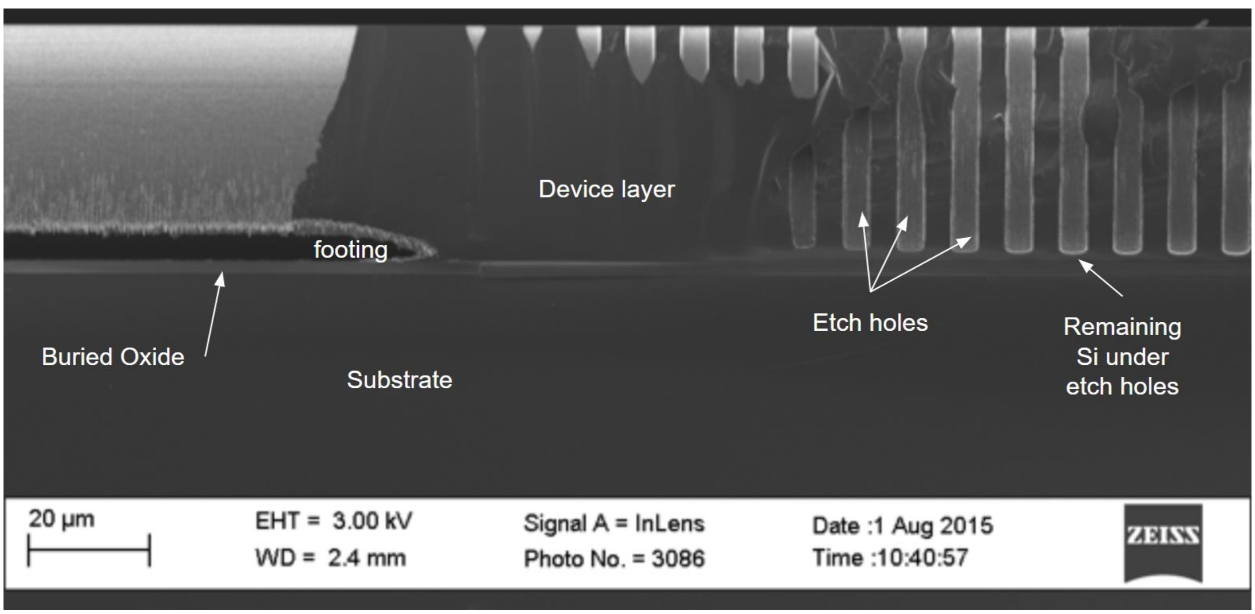
B. $\sigma_1 = \frac{Ea * y(L)}{L^2}$

$L = 300um, y(L) = 1um\ and\ a = 1um$

σ_1 =11u*E

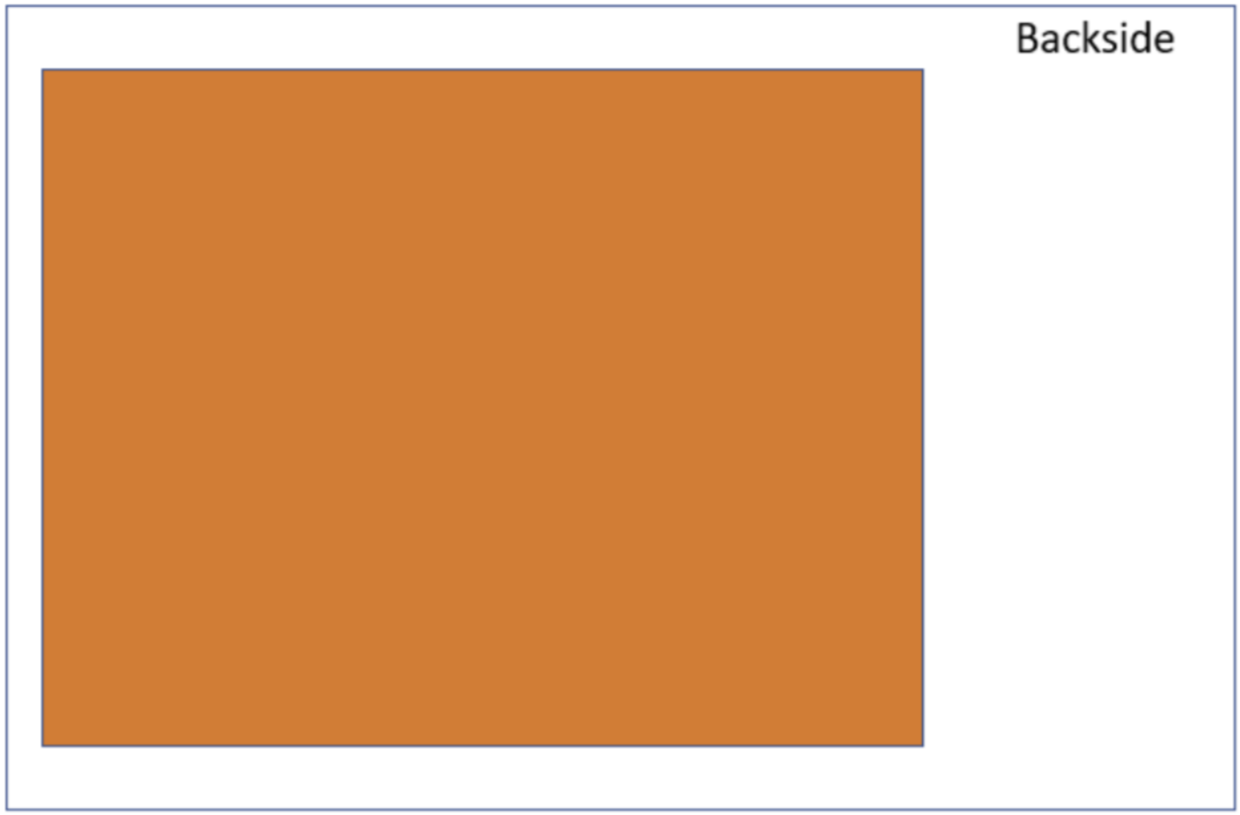
2. [8 points]

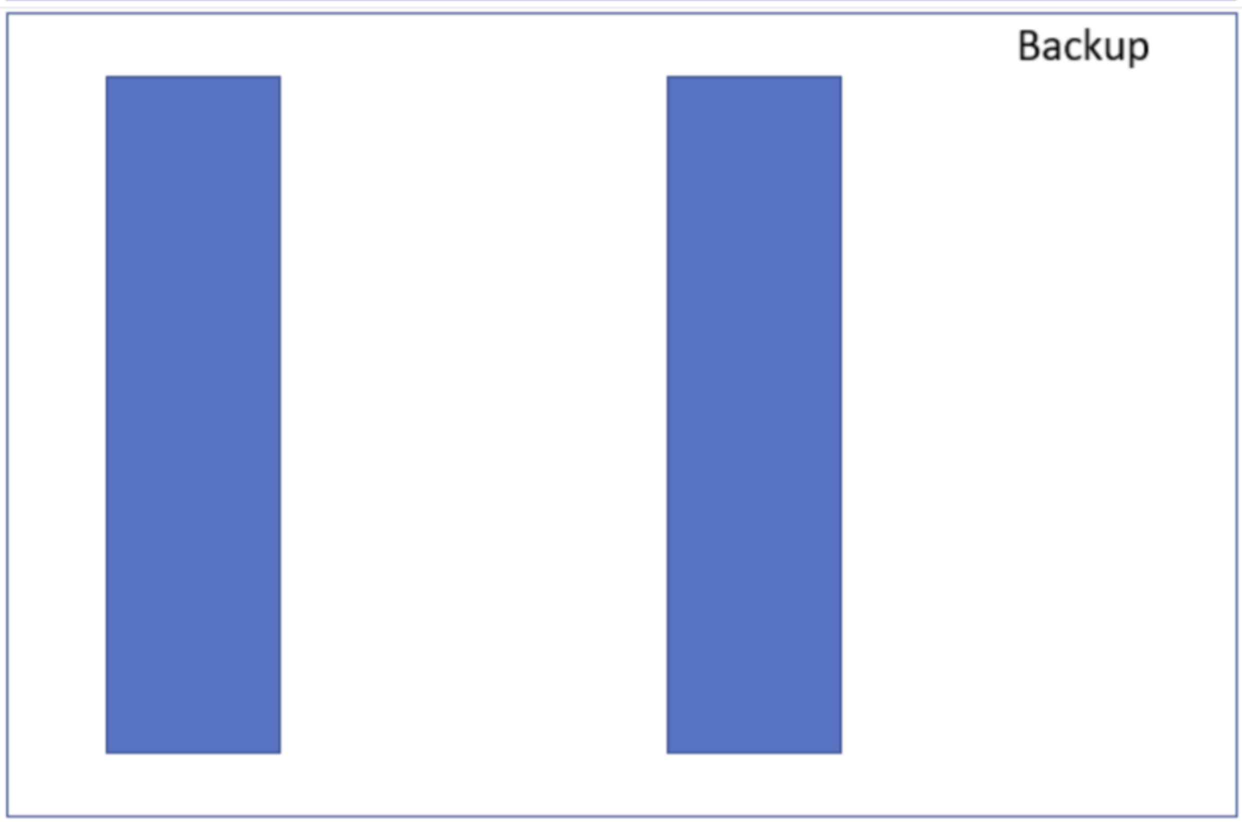
a. [6 points] ~2um of Si remaining underneath the etch holes

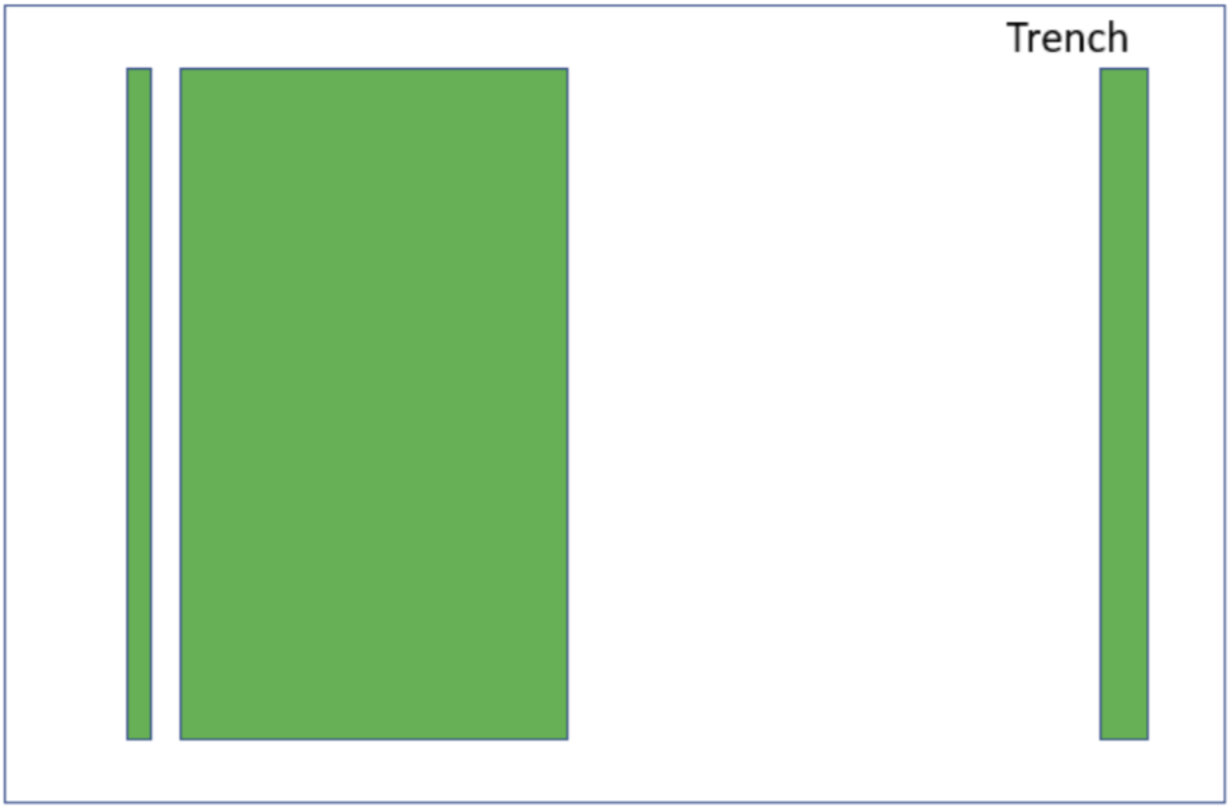


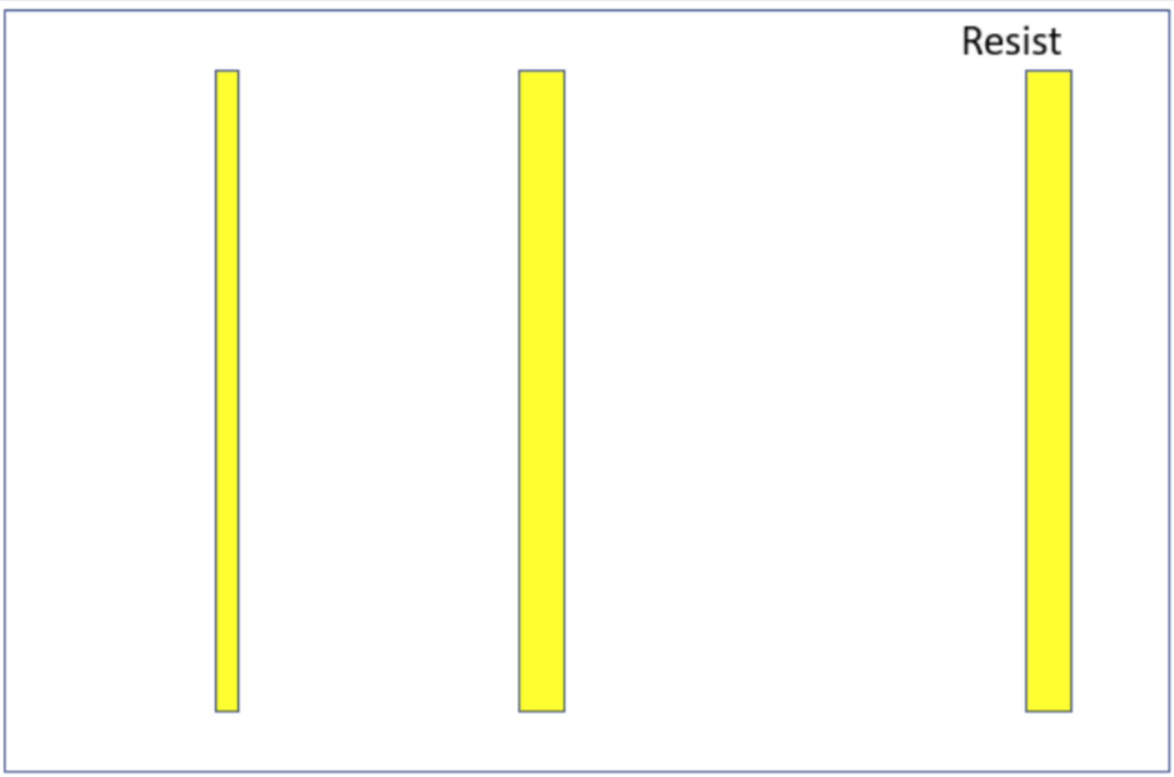
b. [2 points] The spring disappeared because of thermal effects during DRIE, as a result of footing. During the device layer etch, once all of the silicon was consumed in a trench, the ions started to bounce off of the SiO2 and resulting in attacking the sidewalls at the base of the trench: footing. If severe enough, as in this case, this footing can eat through the width of the spring. Once that happens, the thermal conductivity of the spring to the substrate drops dramatically, and the thermal input due to the plasma etch causes the temperature of the middle of the beam to shoot up hundreds of degrees (slides 64 and 65). This causes the beams to be etched away, probably because the protective polymer on the sidewall is compromised (Teflon melts and decomposes at 327C), allowing the SF6 plasma to attack the sidewalls. Give yourself 1 pt if you mentioned footing, and another for thermal.

3. [10 points]
    a. [3 points] Hot phosphoric acid This has an etch rate of 4.5nm/min so it would take about 45 minutes to etch 0.2um SiO2 would make a good masking layer for this because it's etch rate is considerably slower
    b. [3 points] There are 4 main HF etchants: 10:1, 5:1BHF, vapor HF and 10:1 BHF Ti Etch: this is a dilute HF solution is it etches very slowly HF vapor (this is a great release etchant). There are 4 different HF etchants, there are 11 silicon dioxides, so there are at least 44 answers to the question "What is the etch rate of silicon dioxide in HF?" 1 pt for getting at least 2 different HF etches 1 pt for getting at least four different silicon dioxides 1 pt for multiplying the two numbers to get an answer. The "HF" in DRIE stands for High Frequency, not hydrofluoric acid.
    c. [2 points] Table II Si(100) etches 1100nm/min in KOH and from Table VII Parylene-C etches 0.42nm/min in KOH. So to etch through 550um of Si would take 500 minutes, which would etch 210nm. You'd need at least 210nm for this etch. However, you typically do at a 20% overetch on non-critical features, especially on very deep etches like this so you'd probably use 300nm but full credit for 210nm.
    d. [2 points] From Table III 5:1 BHF etches thermal oxide (usually the type of oxide in an SOI wafer) 0.1um/min so it'd take 100minutes to etch 10um. Table VII states that Parylene-C etches 0.16nm/min in 5:1 BHF so it'd etch 16nm in that time. Full points for anything reasonable above 16nm.
4. [34 points]
    a. [2 points] Grow 1um wet thermal oxide; 2. Clean in piranha, rinse, dry; 3. touch wafers together (Prebond); 4. Anneal 1 hour, 1100C
    b. [12 points]
        i. [2 points] Trench Mask: Front: Thermal oxide, Resist Mask: Front: LTO, Backup Mask: Back: Thermal oxide, Backside Mask: Back: PR
        ii. [6 points] The trick here is to look at figure 4A, which shows all of the masks already done. The magic of this process is that all of the lithography gets done early, and then the complex 3D structure gets etched without any additional lithography needed.


Backside


Backup





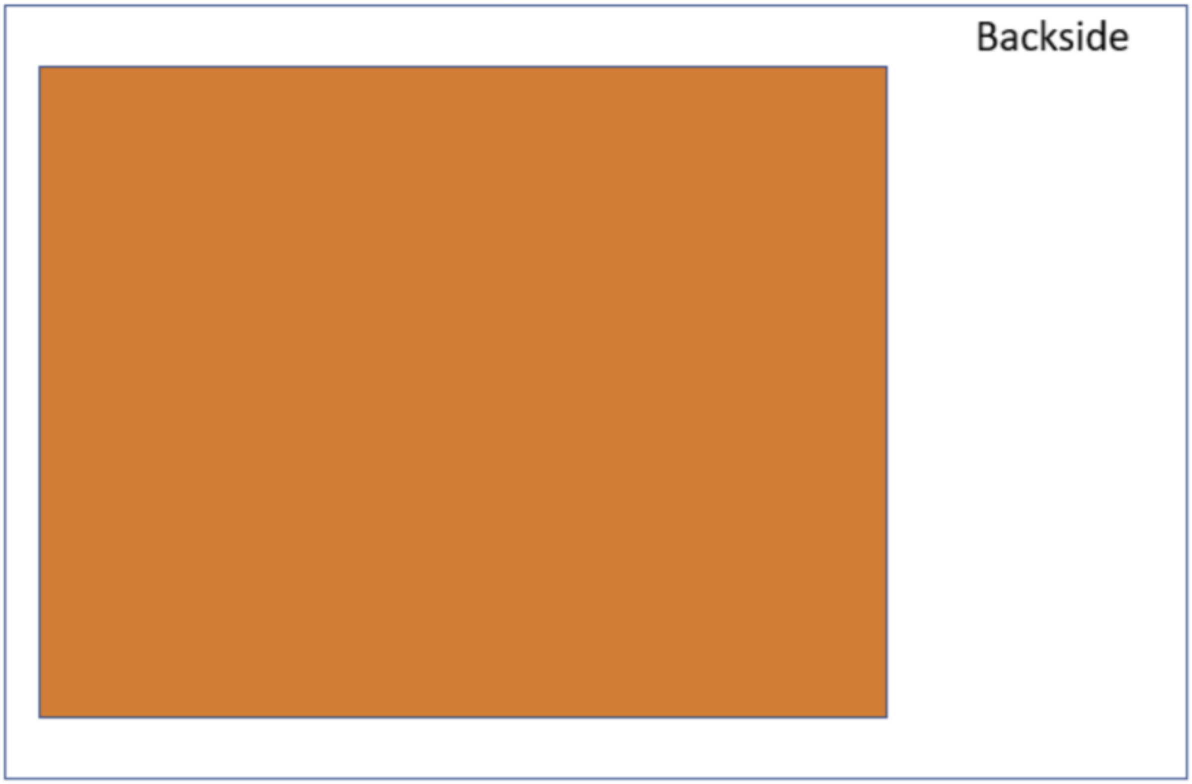
iii. [2 points] The first backside DRIE defines the upper and high beams The minimum backside feature is 30um and there is also a ±10um lateral error in the backside etch. The lower beam (defined by the frontside LTO) must be >10um from the edge of the Backup Mask and the Upper beams then must also be >10um from the edge of the Backup Mask. This means that the minimum gap between Upper and Lower beams is is 20um. The high beams must be >10um if they're within 10um of the edge of a Backup Mask.

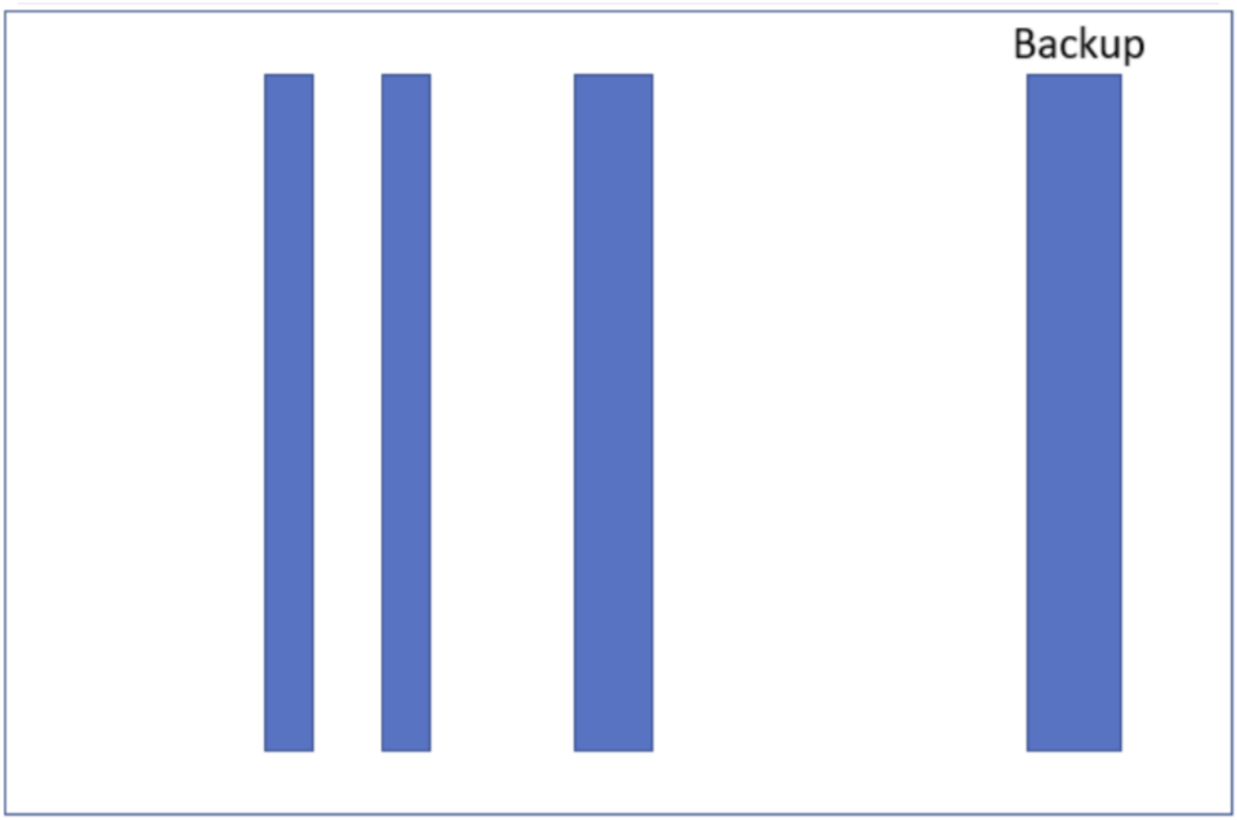
iv. [2 points] No. Because of the minimum gap above, the forces will be much lower than you'd like. It's actually even worse than just the 20um minimum separation. If you think about the masks that you'd need to make alternating low/high beams, you have to add in the minimum feature size on the backside wafer as well. Also, there is no vertical overlap of Upper and Lower beams, but that is a smaller effect.

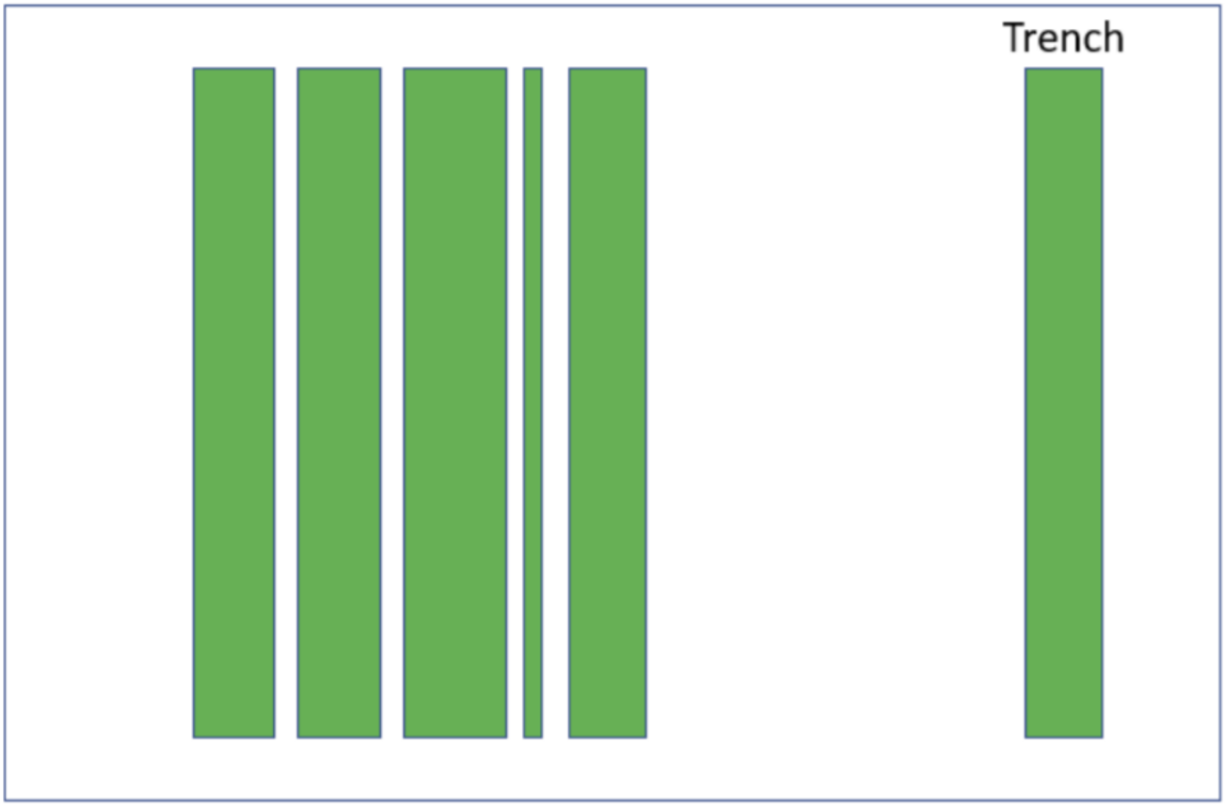
c. [16 points]

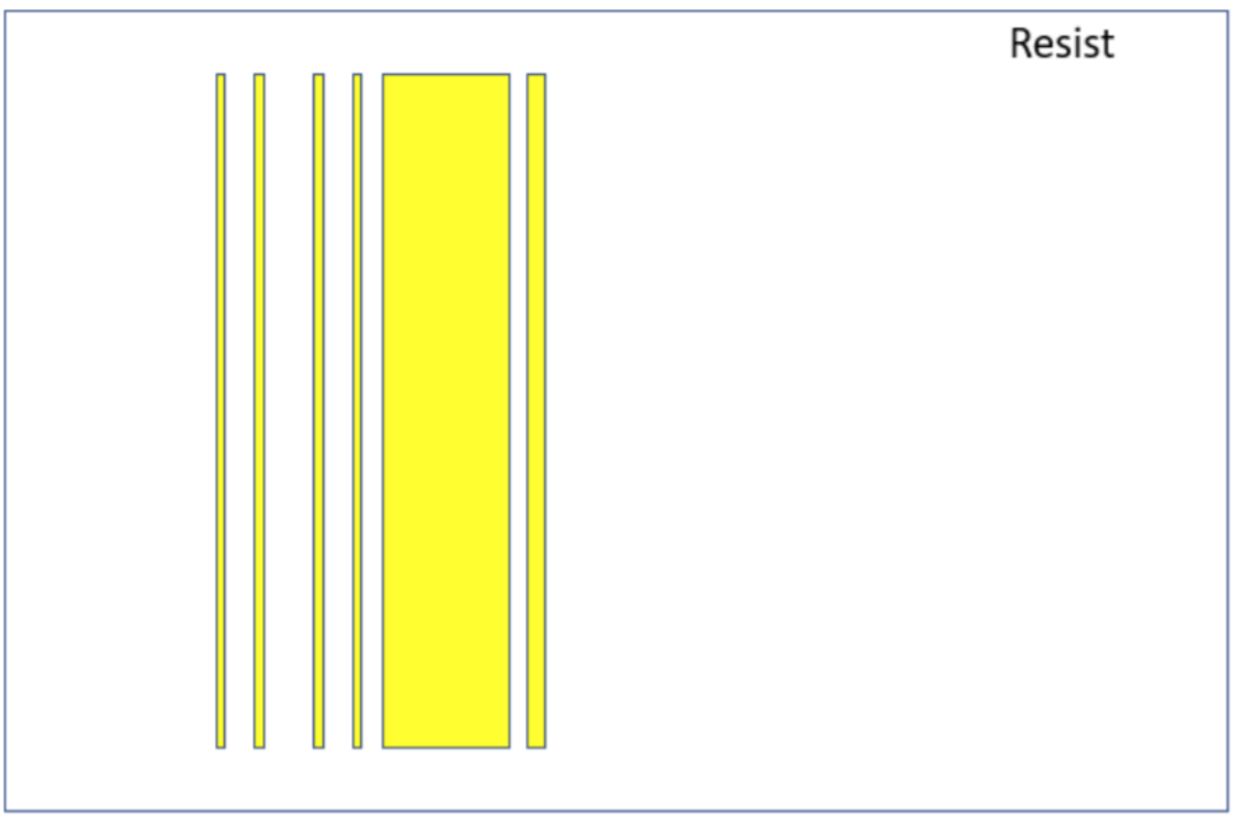
i. [2 points] Trench: Front: Thermal Ox, Align: Front: LTO, Backside: Back: PR, Backup: Middle: Thermal Ox

ii. [6 points] Here you want to look at figure 8A to get what all of the masks look like.


Backside


Backup


Trench


Resist

iii. [4 points] The Upper and Lower beams can be right next to each other because the Backup mask is defined on the buried oxide, not the backside of the wafer, so there is no large lateral error due to DRIE sidewall angle, and the minimum feature size is the same as on the front side. The Upper and Lower beam thicknesses are defined by different masks (Trench and Backup determine which will be Lower and Upper, respectively), but their planar locations (layout view) are all defined by a single mask: Align. That lets them have accurate line/space – no alignment necessary.

iv. [2 points] Yes. Good alignment and overlap between Upper and Lower beams

v. [2 points] No. The backside etch that defines the bottom of the Upper and High beams and the frontside etch that defines the top of the Lower beams overlap. Thus if you put LTO in the middle of a Backup hole, all the Si would be etched away.

d. [4 points] These are all based on attractive forces. An upwards movement comes from turning on both fixed electrodes which are above the movable plate (V1 and V4): attracting it upwards. To move it down, both fixed electrodes are below the movable plate are turned on (V2 and V3). To rotate clockwise the fixed electrode to the right below the movable plate is turned on (V3) to attract the right side of the movable plate down, while the fixed electrode to the left above the movable electrode is turned on (V4) to pull it up. This results in the plate rotating clockwise. To rotate counterclockwise the left fixed electrode below the movable plate and the right fixed electrode above it are turned on (V2 and V1).

5. [8 points]

a. [2 points]

$$2\gamma_{la} * S^2$$

1 pt for something involving gamma and an area, 1 pt for correct.

b. [2 points]

A simple approximation is work=$F_{average}$*distance

You found the energy change (work) in part a and the distance is αS

$F_{average}$=work/distance = $2000\gamma_{la}S$=$144\frac{N}{m}S$

c. [2 points] Weight is a force Plugging in 144mN 144uN

d. [2 points]

Density of Si=2300kg/m^3

$144\frac{N}{m}S$=2300kg/m^3 * S^3

S=0.25m

This is nuts! This cube weighs almost as much as you do. Surface tension is powerful stuff!

6. [12 points]

a. [2 points]

$$4S\gamma_{la}$$

b. [2 points]

Assuming the gap is much smaller than the size of the plates

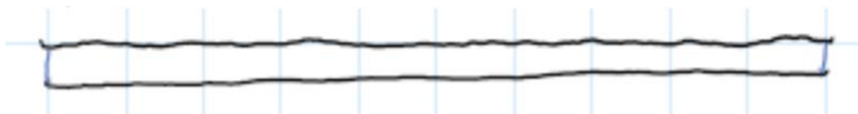
$$S^2 \Delta p = 4S\gamma_{la} \ and \ \Delta p = \frac{\gamma_{la}}{r}$$

$$r=\frac{S}{4}$$

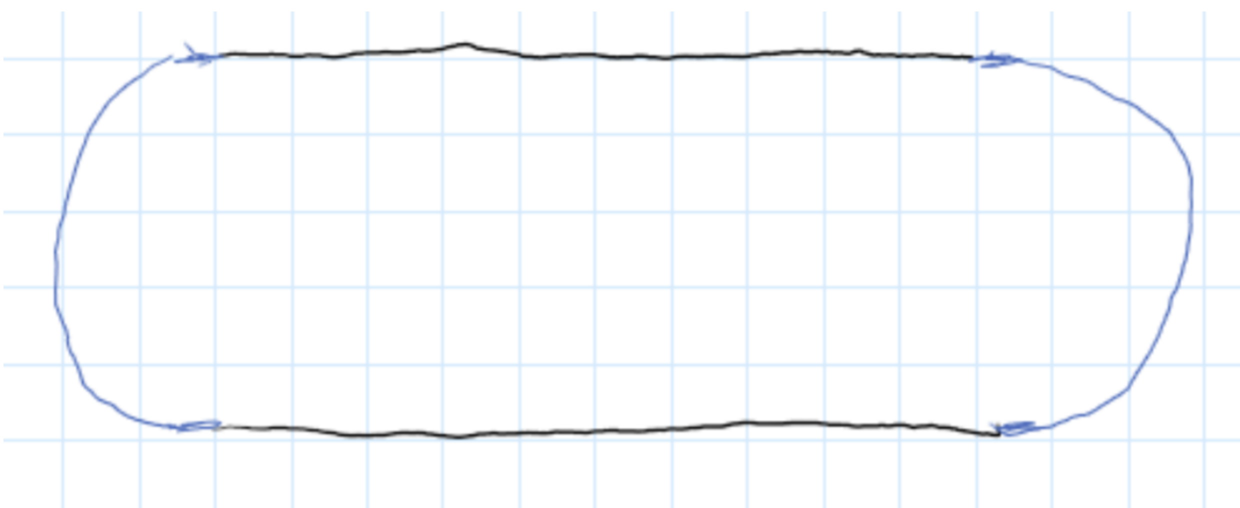
c. [6 points]

i. 1 point for any attempt, 1 point for nearly vertical meniscus (r=2.5um looks pretty flat with a 1um gap)

ii. [2 points] 1 pt for any attempt, 1 pt for nearly vertical meniscus (r=2.5um looks even more flat with a 0.1um gap flat)



iii. [2 pts – 1 pt for any attempt, 1 pt for at least some bulge on the sides.] Here the gap is the same magnitude as S so we need to include both radi in the Laplace pressure calculation, so our r is now =5um. The reality here is that now the surface tension force is not pulling directly down, so another of our assumptions is not correct. But it will look more rounded on the edges than the previous two examples



d. [2 points]

Surface tension: $4S\gamma_{la}$=28.8mN

Weight: $2300\frac{kg}{m^3} * 2um(100um)^2 * 10\frac{N}{kg} = 4.6 * 10^{-10}N$

So the force from the surface tension is more than a millions times greater than the weight of the plate

7. [1 point] It explodes