EE245, Fall 2001

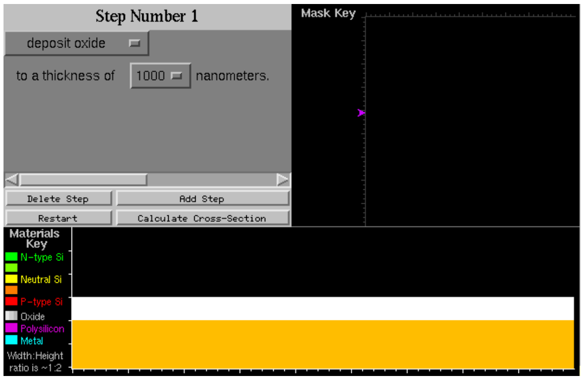
Homework 4 solutions

Process-Related Exercises:

problem 1

To fabricate a cantilever beam:

Step 1: deposit sacrificial oxide layer, 1000 nm

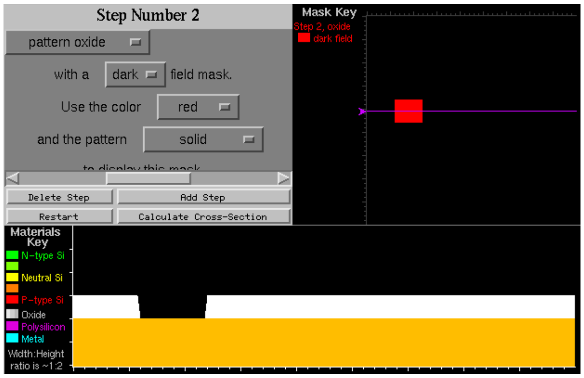


Step Number 1

deposit oxide

to a thickness of 1000 nanometers.

Step 2: pattern oxide with a dark field mask



Step Number 2

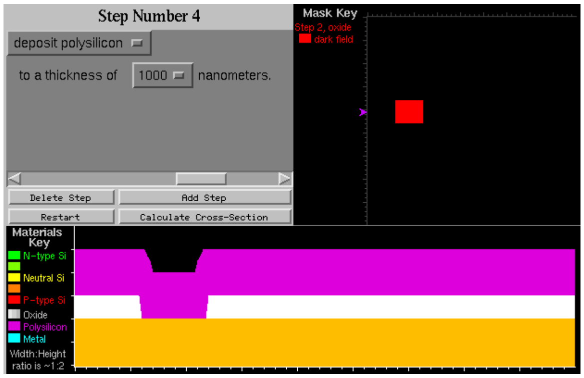
pattern oxide

with a dark field mask.

Use the color red

and the pattern solid

Steps 3 & 4: deposit polysilicon, 1000 nm each step (this is just because the homework picture looks like it had 1000 nm oxide followed by 2000 nm polysilicon, and maximum allowable deposition on the SIMPLer site is 1000 nm).



Step Number 4

deposit polysilicon

to a thickness of 1000 nanometers.

Step 5: pattern polysilicon with a clear field mask.

Step Number 5

pattern polysilicon

with a clear field mask.

Use the color pink

and the pattern solid

The last step of course is to release the cantilever from the substrate by wet-etching the sacrificial oxide layer in HF.

problem 2

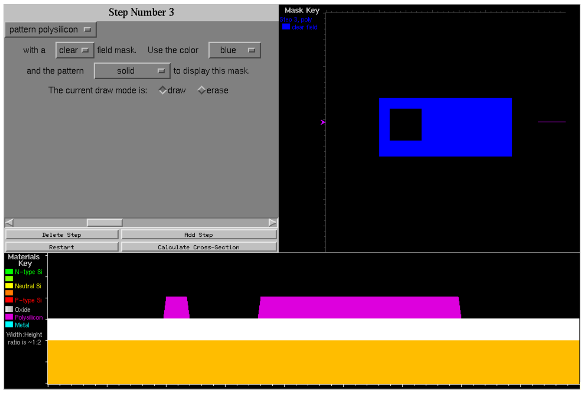
To fabricate a hinged plate:

Step 1: deposit oxide, 1000 nm

(**result** is same as in step 1 above)

Step 2: deposit polysilicon, 1000 nm

Step 3: pattern polysilicon with a clear field mask to define the moving plate.



Step Number 3

pattern polysilicon

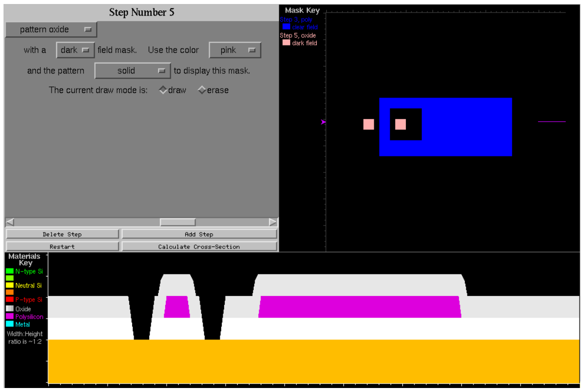
with a clear field mask. Use the color blue

and the pattern solid to display this mask.

The current draw mode is: ◇draw ◇erase

Step 4: deposit oxide, 1000 nm

Step 5: pattern oxide with a dark field mask to define the anchor points to substrate.



Step Number 5

pattern oxide

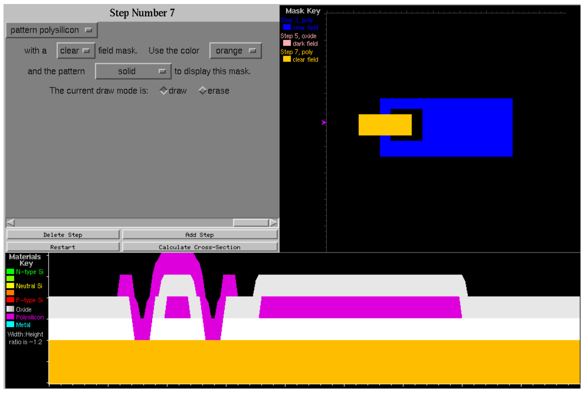
with a dark field mask. Use the color pink

and the pattern solid to display this mask.

The current draw mode is: ◇draw ◇erase

Step 6: deposit another sacrificial oxide layer

Step 7: pattern the 2nd polysilicon layer with a clear field mask to define the "bridge" that holds the plate to the substrate.



Step Number 7

pattern polysilicon

with a clear field mask. Use the color orange

and the pattern solid to display this mask.

The current draw mode is: ◇draw ◇erase

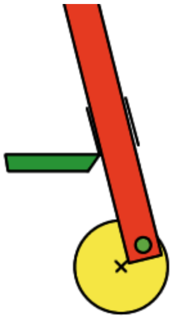
And release the hinged plate by etching away the sacrificial oxide layers in HF.

A few things to watch out for:

- Make sure that the plate can actually move! For example, notice that in this particular example there is a maximum of 3 μm clearance underneath bridge, because this is the height of the two sacrificial oxide layers (1 μm + 1 μm) plus 1 μm for the poly1 layer. If you drew the poly1 mask so that the part under the bridge was wider than 3 μm, then the plate cannot physically rotate up 90°. Also if you make the "bridge" too large, then the plate cannot clear the top of the bridge while rotating up.
- However, if you make the polysilicon part of the plate under the "bridge" too thin, this hinge will be very wobbly.
- On the other hand, the more play there is in the hinge, the less sensitive the design will be to misalignment. If you had zero microns of overlap between the mask in Step 7 and the mask in Step 5, and the anchor openings are only 1 micron wide, then a 1 micron misalignment would be disastrous. So always make sure that the rectangle in Step 7 completely covers the rectangles in Step 5, plus some overlap (maybe 3 μm).

problem 3

I want to make a rotating gear attached to a pushrod crank. For example, we could have the gear attached to the substrate using a pin joint, and then the crank attached to the gear using another pin joint. Design a process flow to accomplish this. Describe your process and sketch out cross-sections (by hand) to illustrate your process. Consider the fact that after the release etch, parts that are not connected to the substrate can fall downwards. Make sure that the crank can turn the gear without colliding into anything. Illustration:



We could start out with SIMPLer, just to see how this process flow might go:

Step 1: deposit sacrificial oxide layer.

Step 2: deposit 1st polysilicon layer.

Step 3: pattern polysilicon layer to define the rotating part (yellow round shape above).

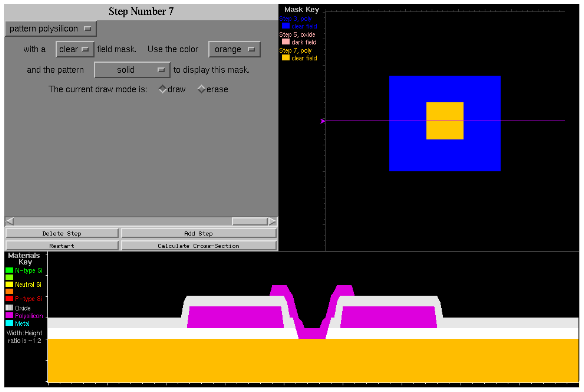
Step 4: deposit 2nd sacrificial oxide layer.

Step 5: pattern 2nd sacrificial oxide layer to open an anchor to the substrate.

Step 6: deposit 2nd polysilicon layer.

Step 7: pattern 2nd polysilicon layer to define the pin (above, the little x in the yellow circle).

So up until now, using SIMPLer, the cross section might look like this (pretend that the squares are actually circles):



Step Number 7

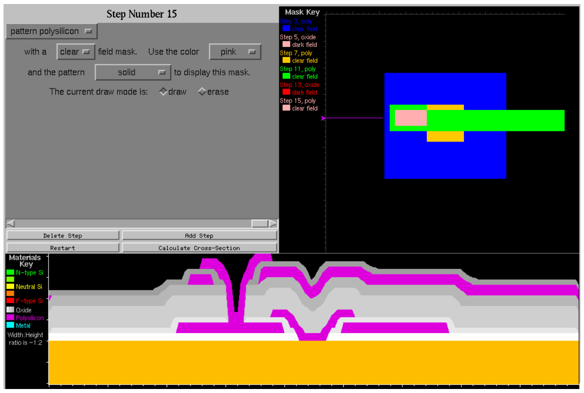
pattern polysilicon

with a clear field mask. Use the color orange

and the pattern solid to display this mask.

The current draw mode is: ◇draw ◇erase

However, now what we need to do is make the pushrod crank. This consists of the red bar, which is attached to the yellow circle by the little green pin. The green pin is actually another pin joint that is anchored onto the yellow rotating circle. If we were to continue using the SIMPLer process, we might then continue by depositing a few more sacrificial layers and polysilicon layers. After a few patterning steps, the cross section might look like this:



Step Number 15

pattern polysilicon

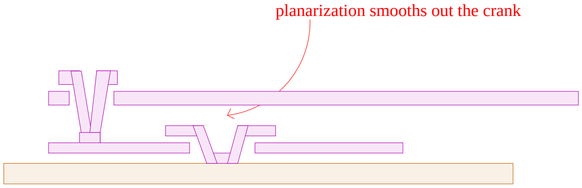
with a clear field mask. Use the color pink

and the pattern solid to display this mask.

The current draw mode is: ◇draw ◇erase

As you can see, the sacrificial oxide layer that follows Step 7 is quite thick. In this picture, it looks like the pushrod crank won't crash into anything if it were to crank the yellow circle around. However, remember that after the release etch, all pieces will fall. After the sacrificial oxide is removed, this means that the little divet in the crank (the crank is the third polysilicon layer, and the pin that holds it to the rotating wheel is made from the 4th polysilicon layer) will get stuck and collide into the divet in the first pin joint (the one that holds the rotating circle to the substrate). So this method is not the best solution.

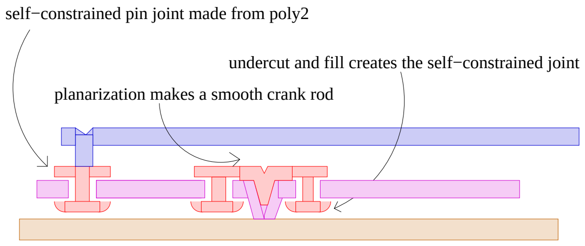
A better way would have been to include a planarization step after a very thick oxide deposition following Step 7. Using chemical-mechanical polishing (CMP), you could deposit for example 6 μm of oxide, and thin it back down - planarize it to 2 μm above the previously highest feature. This gives you a "fresh start," as it were, so that the next few layers will be more planar:



In this way you would be able to crank the gear without colliding into anything. Of course, in this case, the crank would have to really wide (more than half the gear diameter) so that it would stay on top of the middle pin joint all the time and not get caught. Or, if you wanted to keep the crank rod thin, you'd have to put a bump of silicon underneath the arm or use a giant dimple of some sort to hold it up all the time.

A more elegant way ...

is to not start with the SIMPLer model or MUMPS process at all. This structure requires only three polysilicon deposition layers:



The first step is deposition of a sacrificial layer, followed by lithography and etching to open a hole to the substrate. Here the purple layer is the first polysilicon structural layer (poly1). The anchor for the pin joint and the rotating gear are both defined in poly1 (purple). Then there is a wet oxide etch, which will undercut the sacrificial oxide under poly1. The next step is a thin, conformal deposition of another sacrificial oxide layer. This oxide is thin enough so that it won't fill in all of the under cut area. Then we deposit poly2 (red). Since poly2 is conformal, it will fill in the gaps in the undercut regions, as well as deposit a film in the field. Patterning poly2 will create the self-constrained pin joint that holds the crank to the gear, as well as thicken up the pin holding the gear to the substrate. Then we deposit a very thick layer of oxide that is planarized with CMP. Patterning this oxide layer will open a contact to the pin that was formed using poly2. A conformal deposition of poly3 (blue) on top of the planarized oxide and a patterning step will create the crank rod. Finally of course we release the structure in HF. In this case the crank rod is attached directly to the pin and not the gear, so it doesn't have to be as wide.

Note that this 3-poly structure is only possible because of two things (not available in MUMPS):

1. The wet etch undercuts poly1 and allows the formation of the self-constrained pin joint made out of poly2.
2. The thick oxide deposition followed by planarization allows us to make a crank rod that won't collide with anything while turning the gear.

Scaling problem:

20-lb Xerox paper is about 100 microns thick. If you were to scale a sheet of Xerox paper down to 2 microns thick how big would it be?

conserving volume:

So the dimensions of this sheet of paper are 8.5 in x 11 in. This is approximately 0.216 m x 0.279 m. If the thickness is 100 x 10^{-6} m, then the volume of this paper is 6.026 x 10^{-6}m^3. Now we shrink the thickness to 2 μm but keep the same volume. This results in a square that is 2 μm thick and $\sqrt{\frac{6.026*10^{-6}\mathrm{m}^3}{2*10^{-6}\mathrm{m}}} =$ 1.74 m on a side.

scaling linearly:

Or, if we scale the thickness from 100 μm down to 2 μm, then scale the rest of the paper in the same way, the paper would then be:

$\frac{1}{50}(0.216\mathrm{m}) = 4.32$ mm width

$\frac{1}{50}(0.279\mathrm{m}) = 5.58$ mm length

Note that these are thousands of microns! You could make tremendously large structures on the MEMS scale if this were a layer of polysilicon!