ENGG 5404 Micromachining and MEMS

Midterm Exam

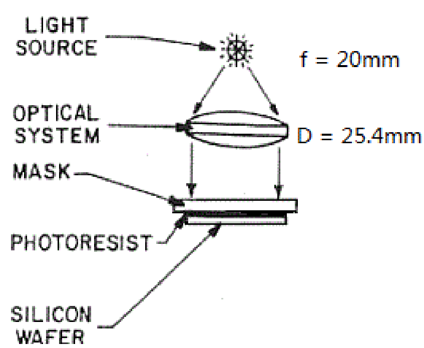
Note:

1. Present all your results and answers in SI units.
2. Calculators are allowed

Total 30 points.

1. Answer the questions in the following figures: **(5 pts)**

a) Determine the type of mask-aligner in the figure below. If this is a camera, what is the f-number? Calculate the numerical aperture (NA) and the patterning resolution, assuming UV light of 400 nm is used; the thickness of the photoresist is 5 μm. **(3 pts)**



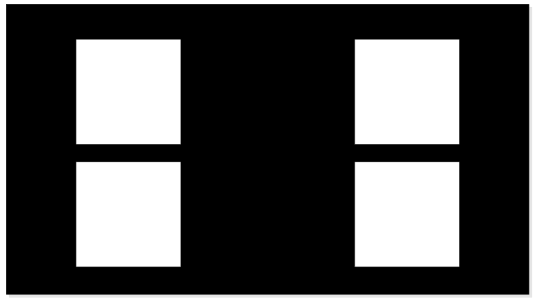
Answer:

f/# = f/D = 0.787

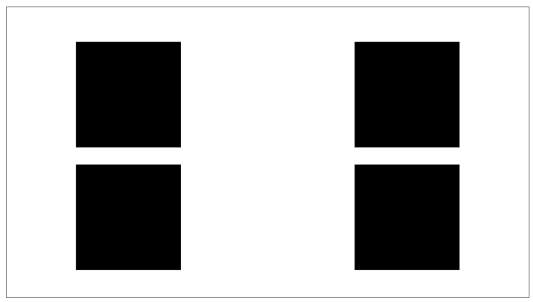
$\tan \Theta = \frac{D}{2f} = 0.635$, hence $sin\Theta = 0.536$. Since n = 1, so NA = 0.536.

Res = $1.5\sqrt{0.4 * 2.5} = 1.5\mu m$

b) We need to micro-fabricate the pattern below with negative photoresists. Sketch the pattern of the mask (Indicate the dark and clear field). **(1 pt)** What are the pros and cons if we use oxide as a masking layer instead of PR for a Deep RIE etching process? **(1 pt)**

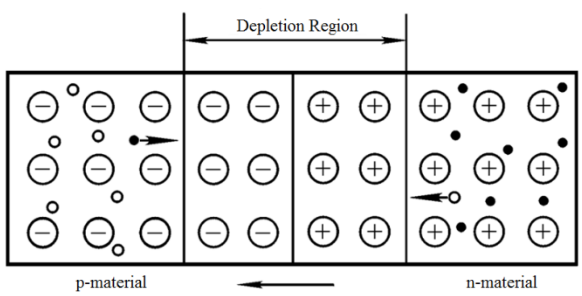


Answer:



Pros: Better resolution.
Cons: More complicated process. Another step of lithography is required.

2. Answer the following questions on p-n junction. **(4 pts)**
   a) Define p-type and n-type semiconductor, describe their properties, and explain the formation of the depletion region, as shown below. **(2 pts)**



Answer:

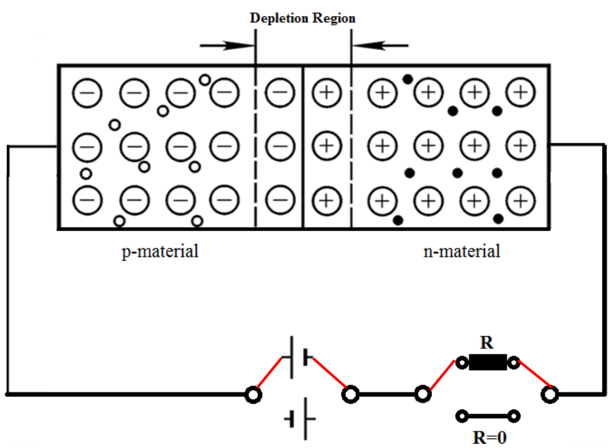
P-type semiconductors are created by doping an intrinsic semiconductor with acceptor impurities. A common p-type dopant for silicon is boron. In addition, p-type semiconductors have a larger hole-concentration than electron-concentration. The phrase 'p-type' refers to the positive charge of the hole.

N-type semiconductors are created by doping an intrinsic semiconductor with donor impurities. A common dopant for n-type silicon is phosphorus. In addition, -type semiconductors have a larger electron-concentration than hole-concentration. The phrase 'n-type' refers to the negative charge of the electron.

Electrons and holes diffuse into regions with lower concentrations of electrons and holes. Electrons migrate into the P-side and holes migrate into the N-side. Departure of an electron from the N-side to the P-side leaves a positive donor ion behind on the N-side, and likewise the hole leaves a negative acceptor ion on the P-side.

Following transfer, the diffused electrons come into contact with holes on the P-side and are eliminated by recombination. Likewise for the diffused holes on the N-side. ***The net result is the diffused electrons and holes are gone, leaving behind the charged ions adjacent to the interface in a region with no mobile carriers (called the depletion region).***

b) Connect the circuit correctly to narrow the depletion region. **(2 pt)**



3. Answer the following questions on wet etching. **(4 pts)**

a) If an anisotropic etchant with etch ratio of {100}>{110}>>{111} is used to etch an (100) single crystalline silicon, prove mathematically that the relative angle between the {100} and {111} directions is ~54.7 degree. **(2 pts)**
Answer:

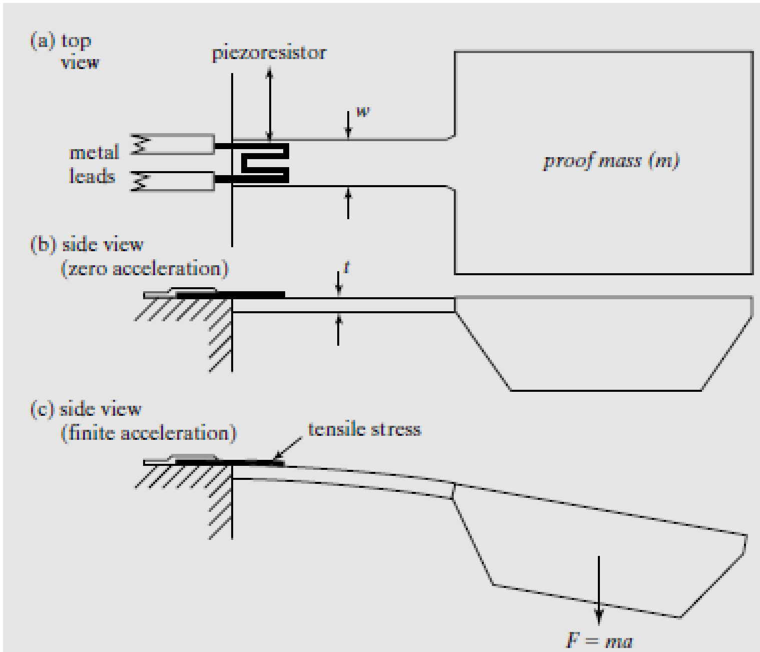
$$cos\theta = \frac{(1,0,0)\cdot(1,1,1)}{|(1,0,0)|\cdot|1,1,1|} = \frac{\sqrt{3}}{3} \approx 0.577$$

Therefore,

$$\theta \approx 54.7°$$

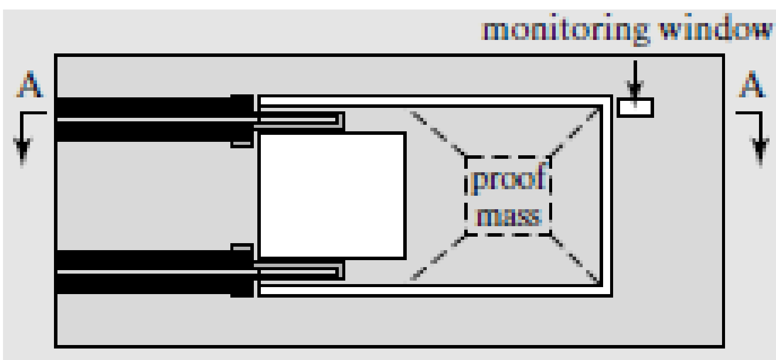
b) Explain why are there hole arrays in the following standing micro-structure? **(2 pts)**
Answer:
To reduce etching time.

4. Figure A shows the conceptual design of a piezoresistive accelerometer. A variation of the design is shown in Figure B.



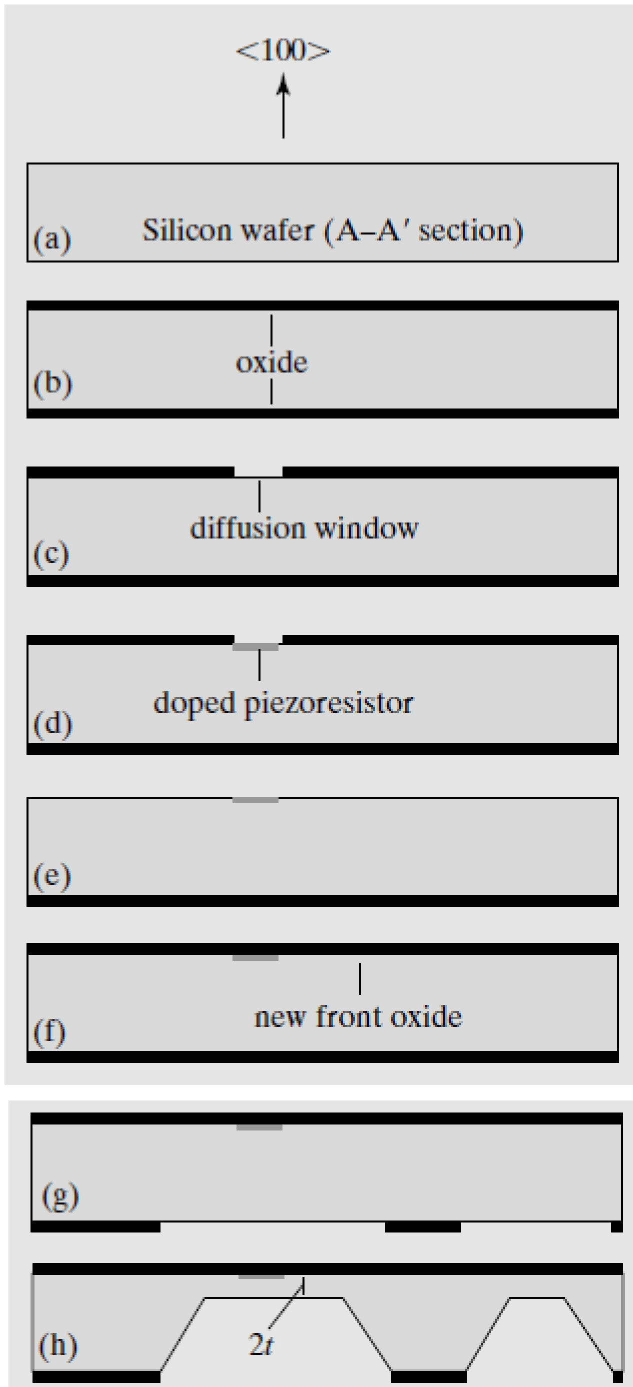
(A)

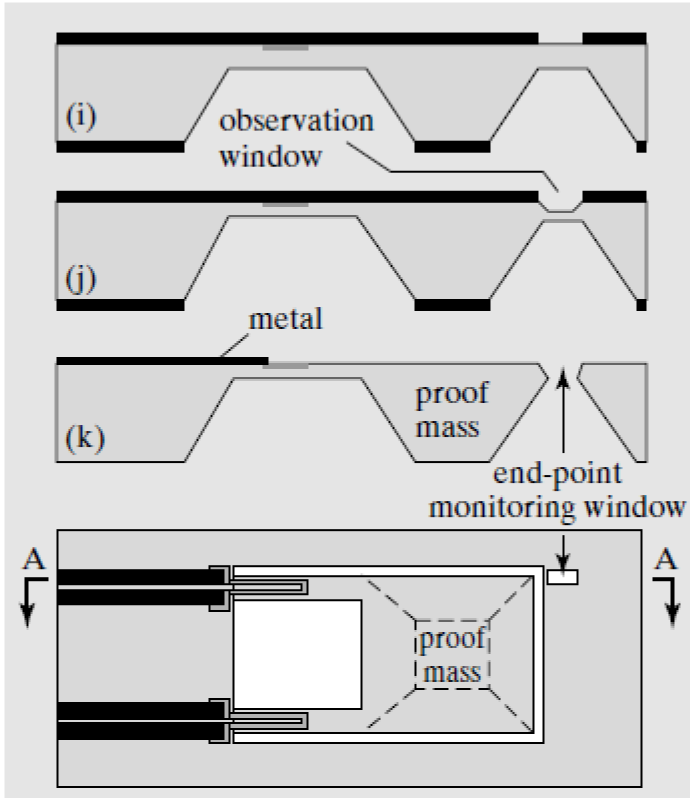
Draw the process flow of the device in Figure B. Specify the possible materials, type of wafers, microfabrication steps and recipes. **(7 pts)**



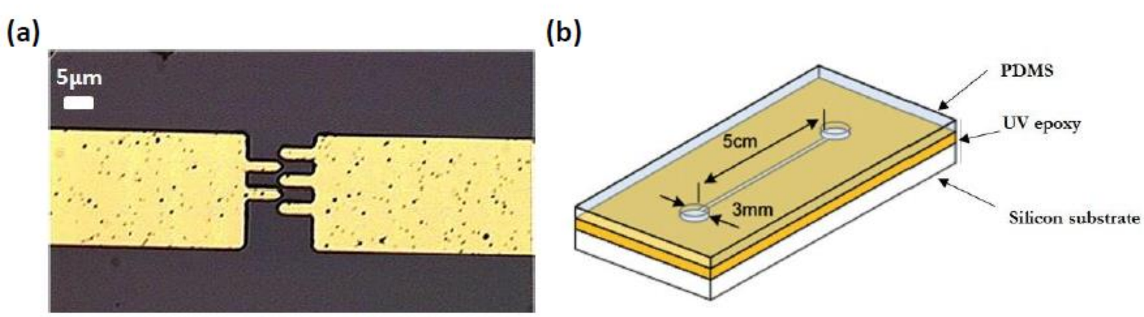
(B)

Answer:


<100>
(a) Silicon wafer (A–A′ section)
(b) oxide
(c) diffusion window
(d) doped piezoresistor
(e)
(f) new front oxide
(g)
(h) 2t

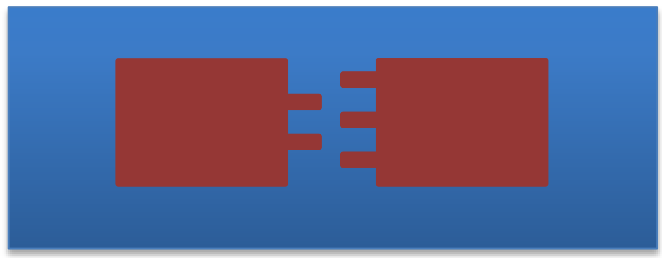


5. Draw the process flow of the following microfluidic device (b), where the direction of the gold electrodes (a) is perpendicular to the direction of the microchannel. Specify the required materials, microfabrication steps and recipes. Hint: (1) Gold electrodes on the silicon substrate must be made first. PDMS channels are subsequently bonded to the substrate with gold electrodes. You may assume that SU-8 photoresist is provided in the clean room and UV epoxy is available for bonding. **(7 pts)**

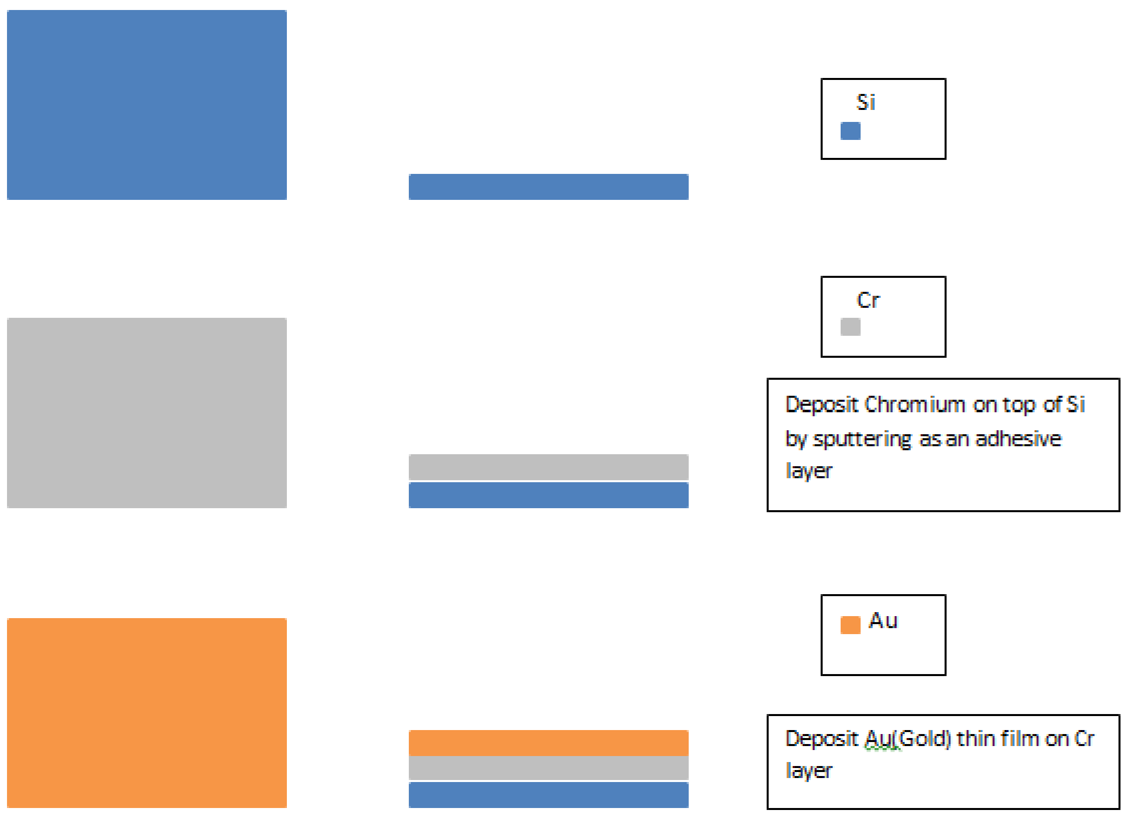


Answer:

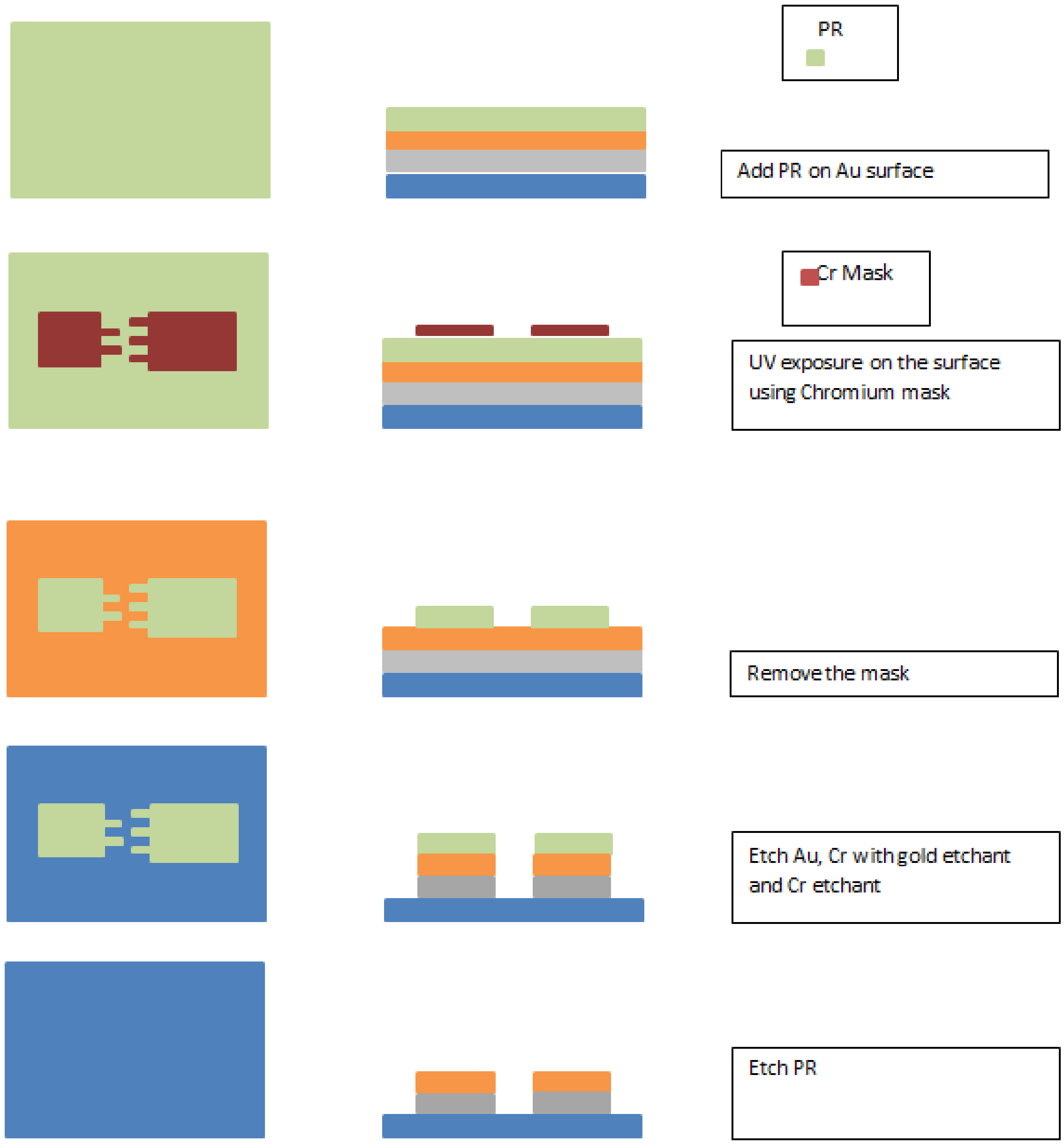
Step 1: Design a Chromium mask because the photoresist is negative



Step 2: The structure is built on Si wafer

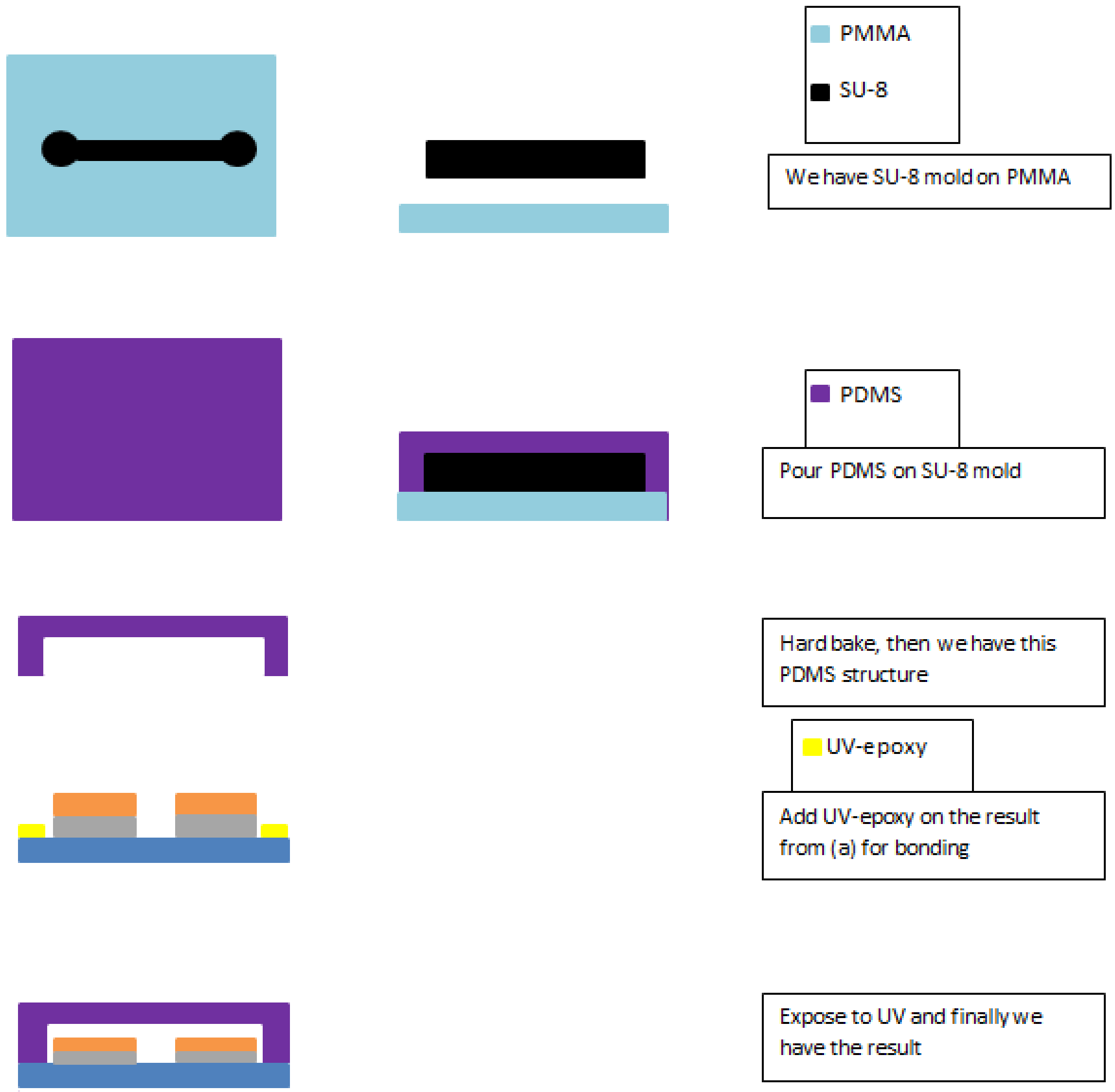


Step 3: Photo-lithography



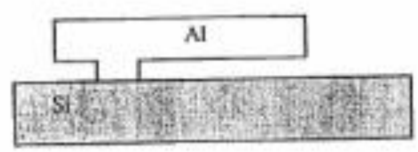
Step 4:

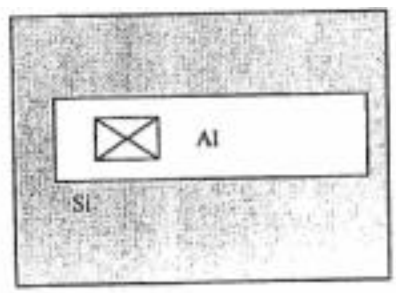
Fabricate the micro-channel and bond it with gold electrodes.


PMMA
SU-8
We have SU-8 mold on PMMA
PDMS
Pour PDMS on SU-8 mold
Hard bake, then we have this PDMS structure
UV-epoxy
Add UV-epoxy on the result from (a) for bonding
Expose to UV and finally we have the result

6. Design a process to make the following aluminum structure on a silicon substrate. Draw cross-sectional pictures for each step needed for your process. Please indicate whenever a mask is needed and draw a top-view of the mask. Also, for each step, please indicate the deposition methods and the etching methods. **(3 pts)**

Note: Entire process must be performed at less than 150ºC.





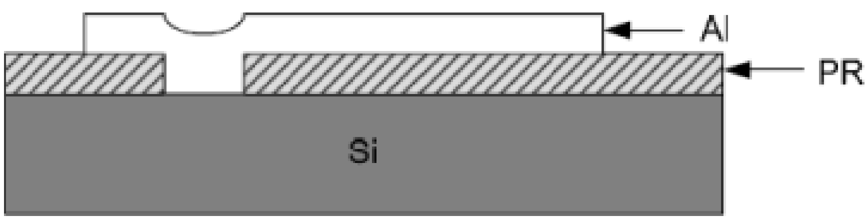
Top View

Step 1

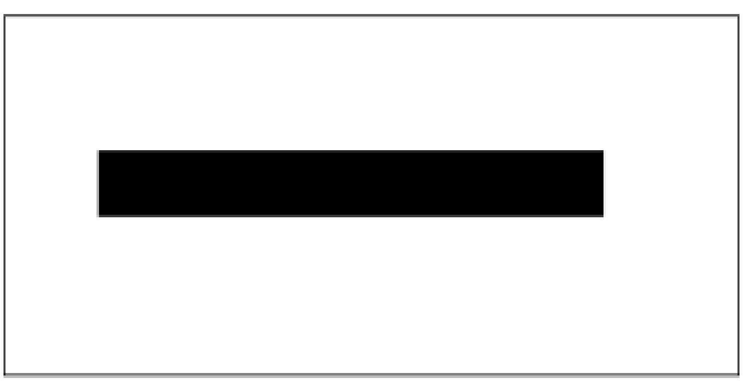
Mask for define PR:

- Deposit photoresist by spin-on
- Define photoresist by lithography + etch in photoresist developer

Step 2



Mask for define Al:



- Deposit Al by sputtering
- Define Al by lithography + etch in phosphoric acid