Surface micromachining and Process flow part 1

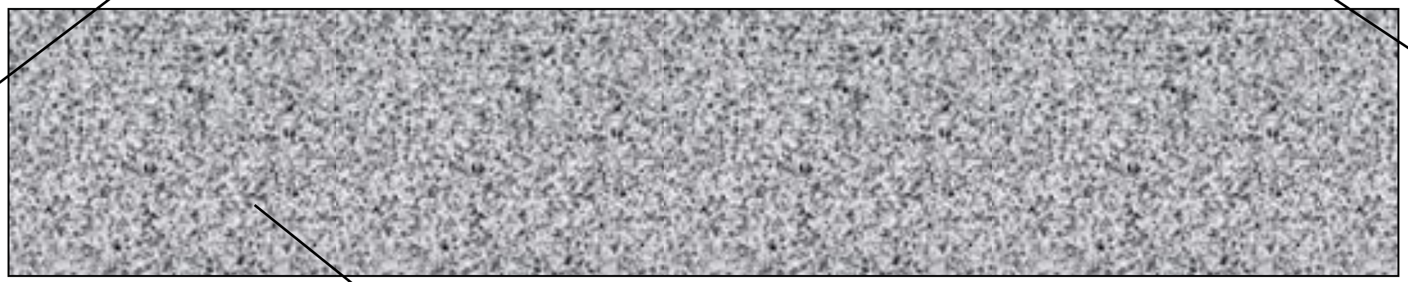
- Identify the basic steps of a generic surface micromachining process
- Identify the critical requirements needed to create a MEMS using surface micromachining
- List common structural material/sacrificial material/etchant combinations used in surface micromachining
- Compare and contrast the relative merits of wet micromachining versus dry micromachining
- Explain the phenomenon of **stiction**, why it occurs, and methods for avoiding it
- Describe the process of **lift-off**
- Explain what is meant by **packaging** and describe the ways in which it present major challenges in MEMS
- Calculate the **resolutions** of the above processes and explain what they depend on and why
- Define the terms
  - **Structural layer/material**
  - **Sacrificial layer/material**,
  - **Release,** and
  - **Die separation**
- Develop a basic-level process flow for creating a simple MEMS device

Surface micromachining example – Creating a cantilever

Deposit poly-Si (________________— the Jenga pieces that remain)

Deposit SiO_2 (________________—the Jenga pieces that are removed)

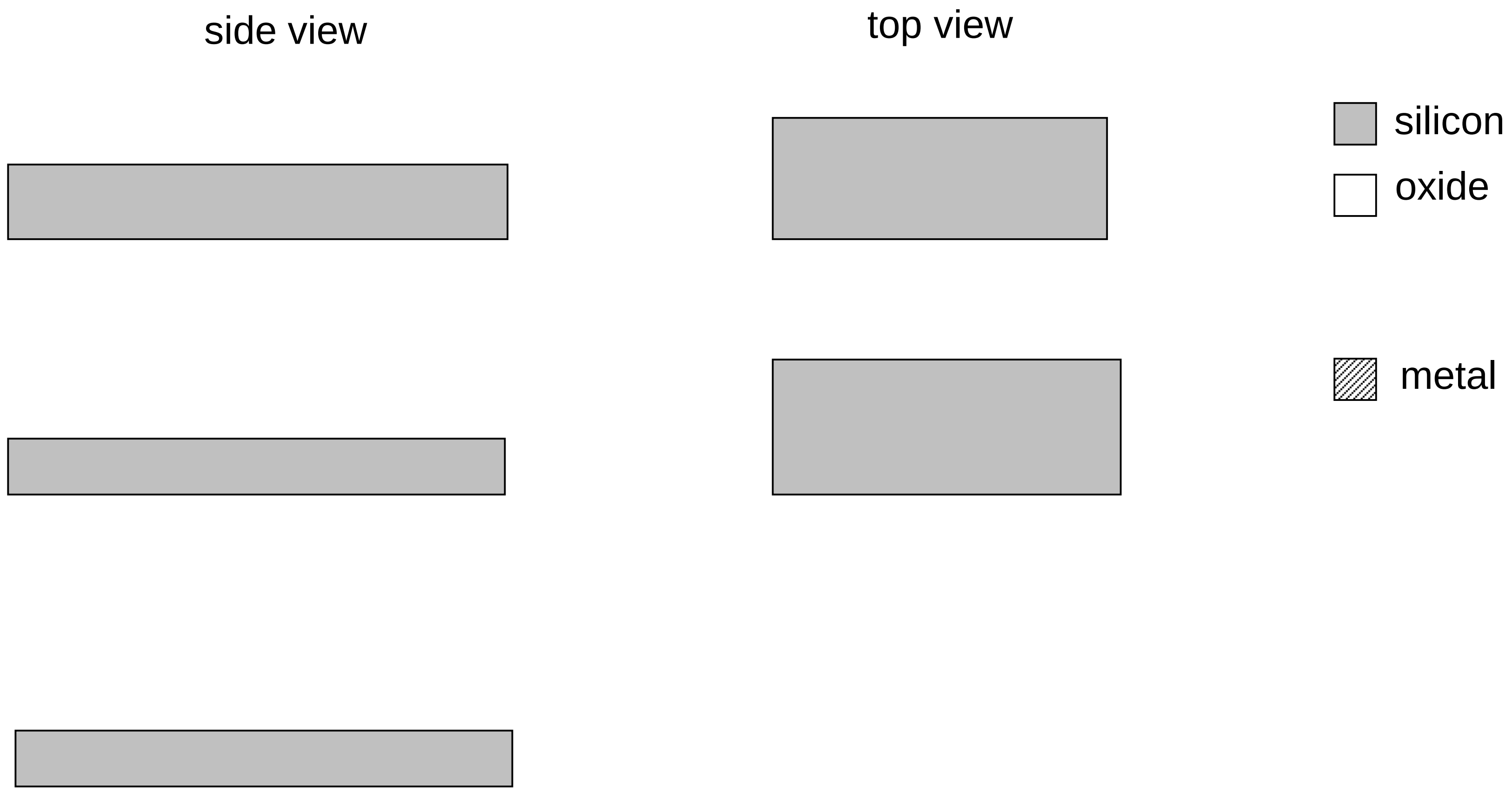
Etch part of the layer.



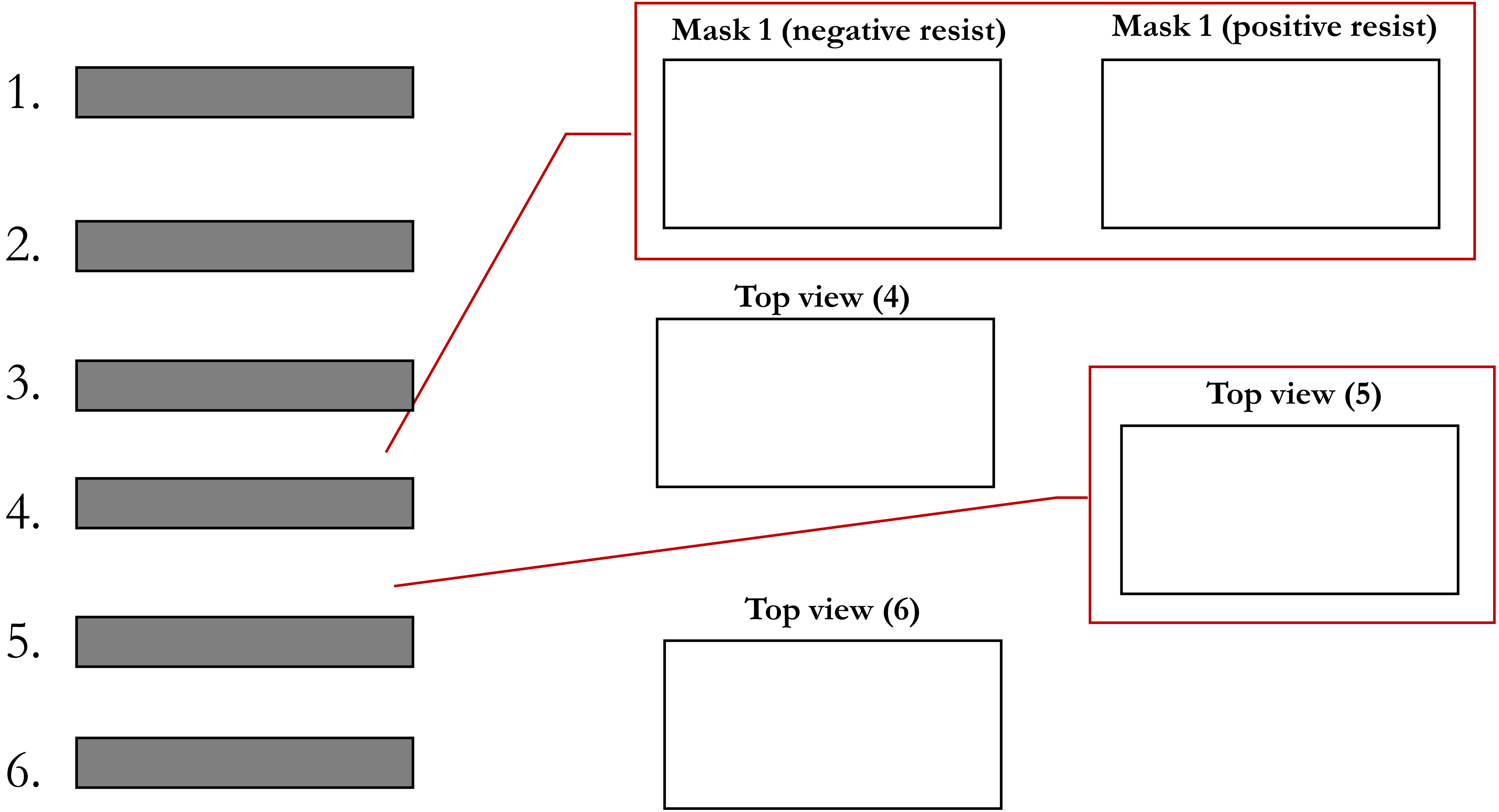
Remove sacrificial layer (__________)

Silicon wafer (Green Lego® plate)

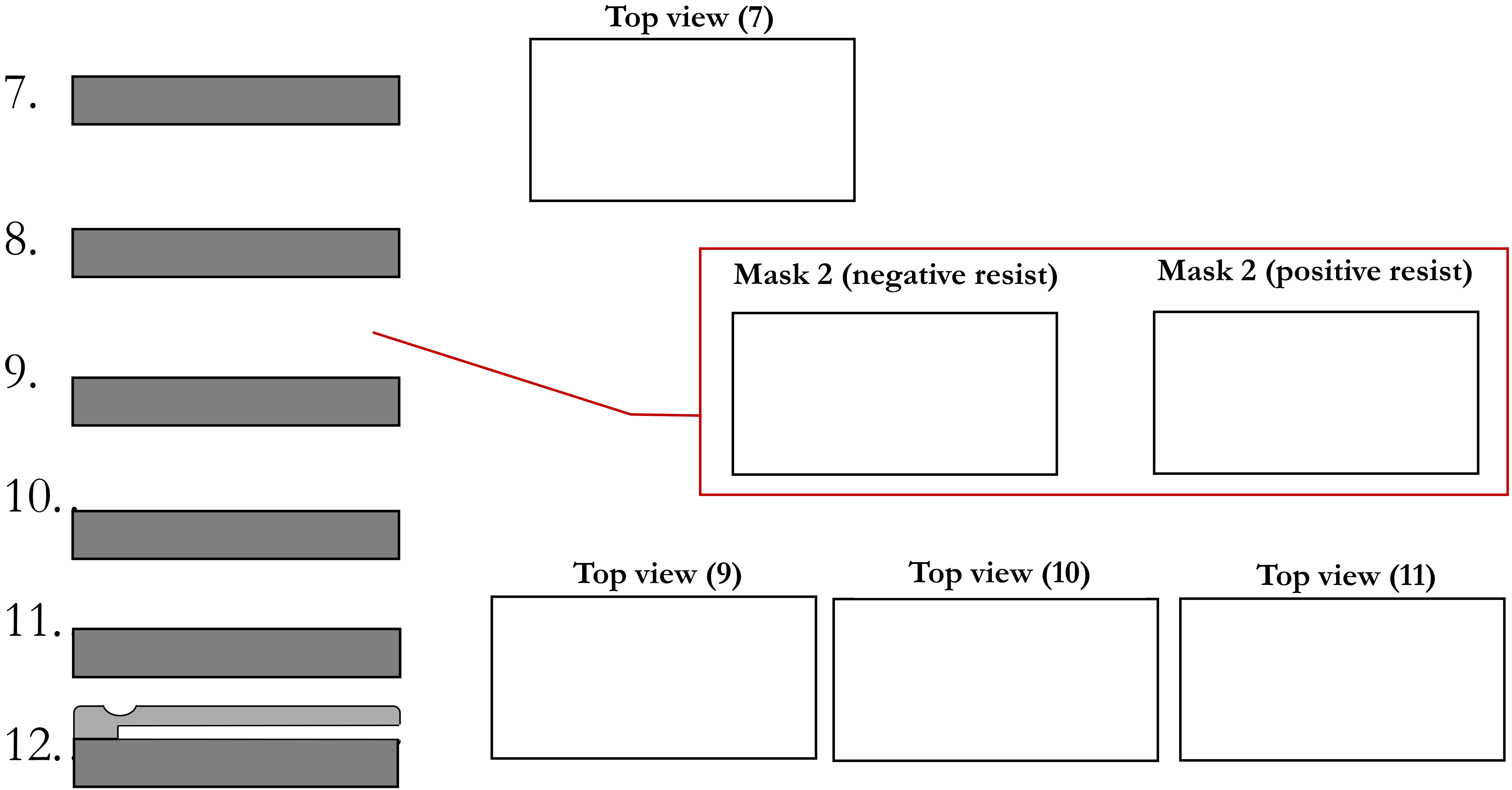
Reminder of the surface micromachining process



Process flow for surface μ-machined cantilever



Process flow for surface μ-machined cantilever



History and processes

- Surface micro-machining (SMM)
- Developed in the early 1980s at the University of California at Berkeley
- Originally for _______________ mechanical structures
- Other processes include
  - Sandia National Lab's SUMMIT (Sandia's Ultra-planar Multi-level MEMS Technology) → five levels possible with four poly layers
  - MEMS CAP's polyMUMPs (Multi User MEMS Processes) → three layers of poly with a layer of metal

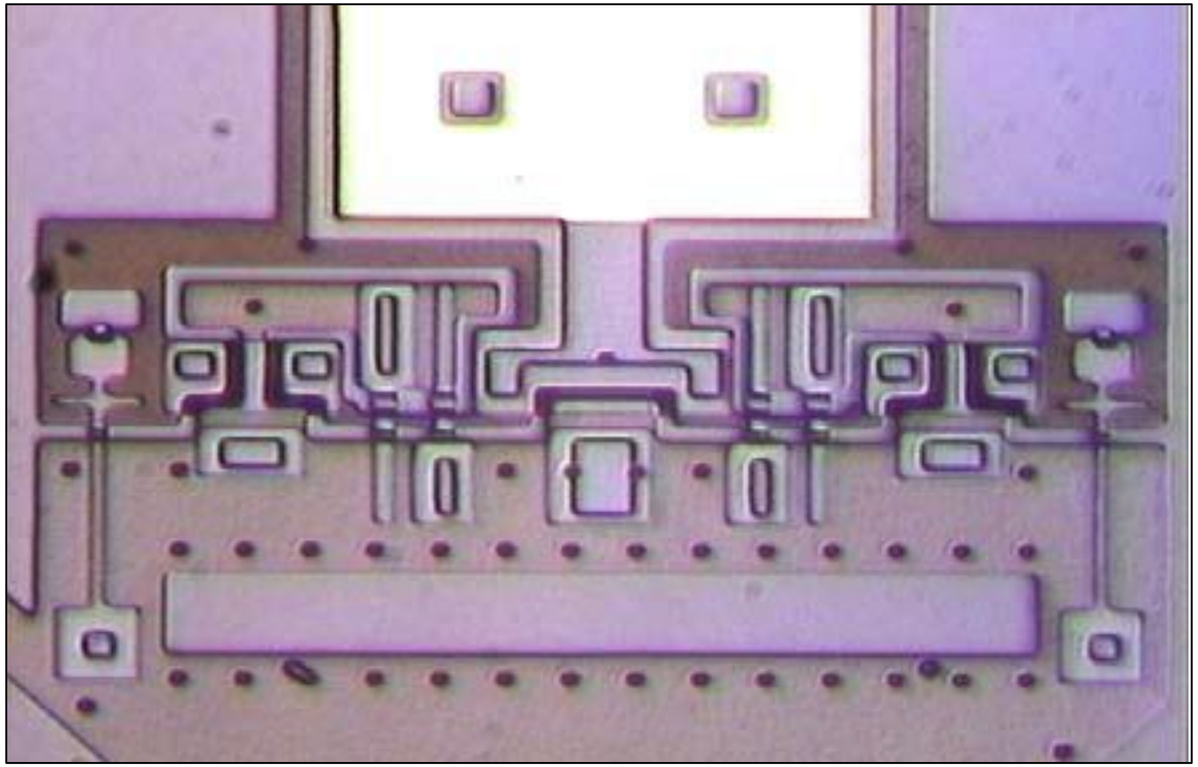


Photo of a PolyMUMPs surface-micromachined micro-mirror. The hinge design allows for out-of-plane motion of the mirror.

Requirements and advantages

- Three to four different materials required in addition to the substrate
    - __________ material (etch rate R_s)
    - ___________ mechanical material (etch rate R_m)
    - Sometimes ____________ and/or ___________ materials (etch rate R_i)
- Many SMM processes are compatible with ________ (complementary metal oxide silicon) technology used in microelectronics fabrication.
- Can more easily ______________ with their control ____________ on the same chip
- Many SMM processes have developed their own

  ____

____

Best results are obtained when structural materials are deposited with good ______________________.

Chemical vapor deposition (CVD)
or
Physical vapor deposition (PVD)

If PVD

Sputtering
or
Evaporation

Common material/etchant combinations for surface μ-machining

Structural material	Sacrificial Material	Etchant
Si/Polysilicon		
Al		
Polyimide		
Si_3N_4		

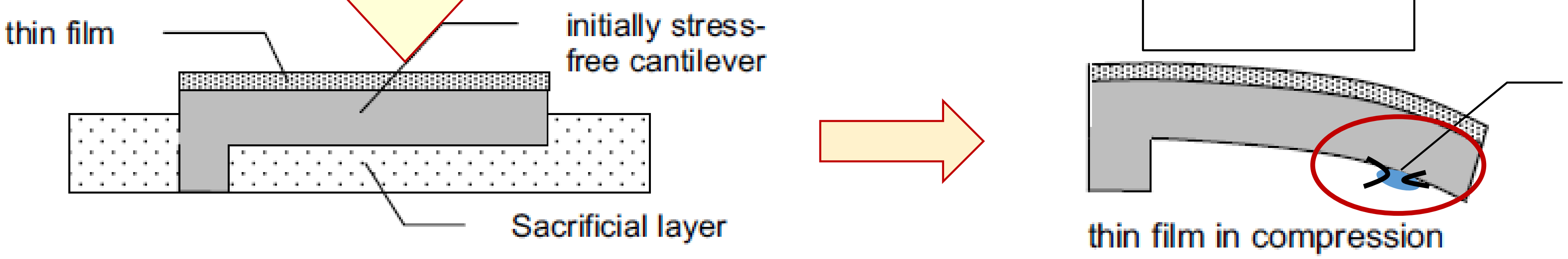
Problems and issues

Wet etching

- 40 years of experience and data in the semiconductor industry
- Ability to remove ______________ ______________
- Very high ______________
- Usually ______________ → always involve ______________________

Dry etching

- Better ______________ than wet etching
- More ______________ (High ________________)
- ______________________________
- No ______________________



Stiction

Stiction = ________ + ________

Stiction = ________ + ________

An example of a ____________________

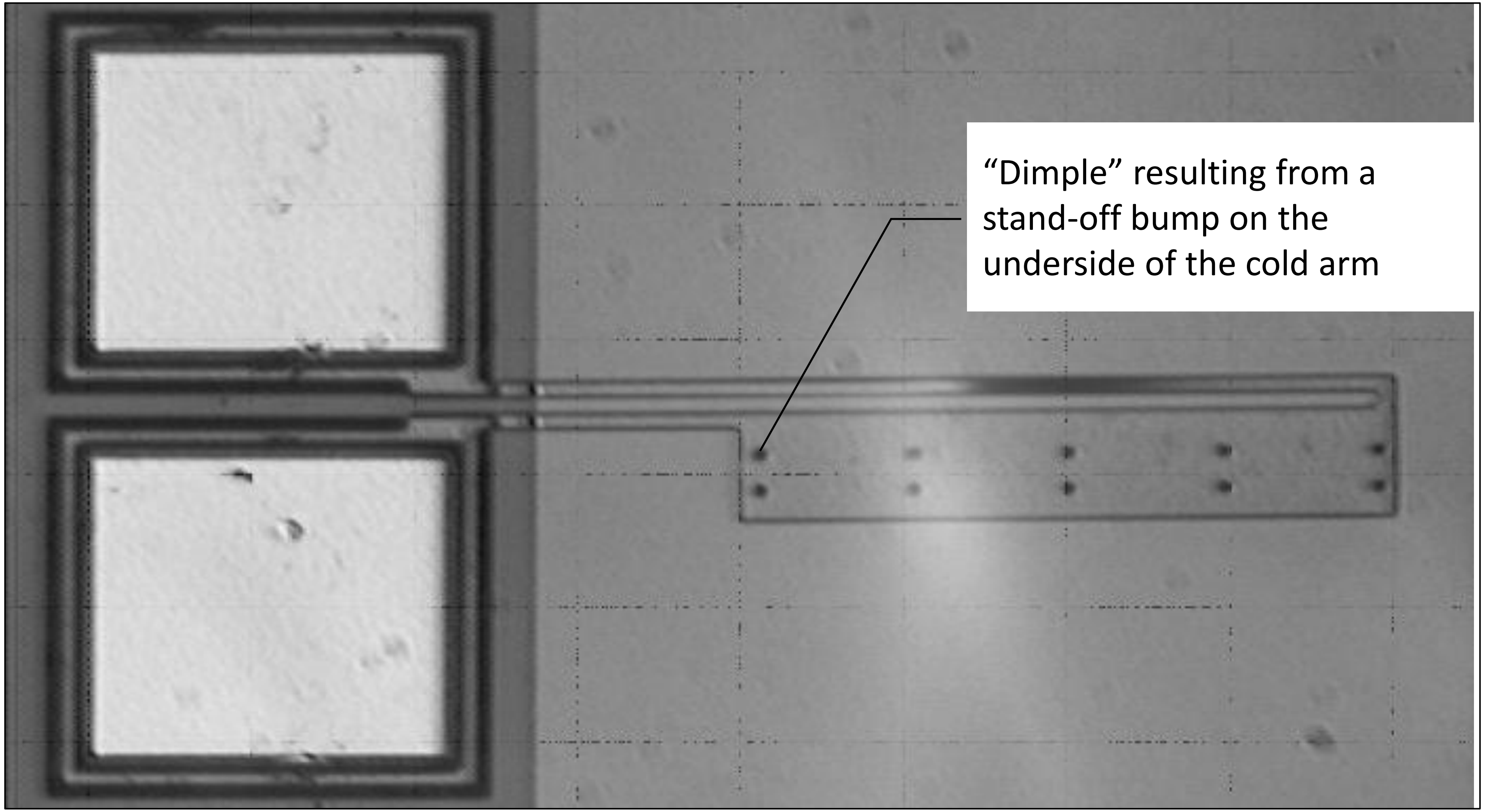
An example of an ______________________

$$\frac{surface\ tension}{restoritive\ force} = \frac{\sigma}{F} \sim \_\_\_\_ \sim \_\_\_\_$$

Ways to reduce stiction

-
-
-

Problems and issues



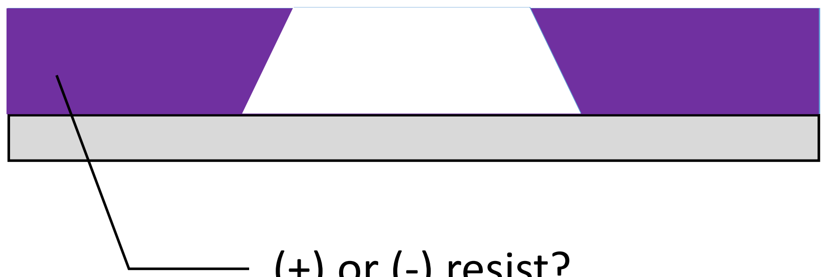
Polysilicon hotarm actuator created using surface μ-machining

Te toca a ti

Explain (with words, drawings, or both) how standoff bumps might be created.

Lift-off

Usually included as an "additive technique" by most authors



1. Photoresist is spun on a wafer and exposed to create pattern

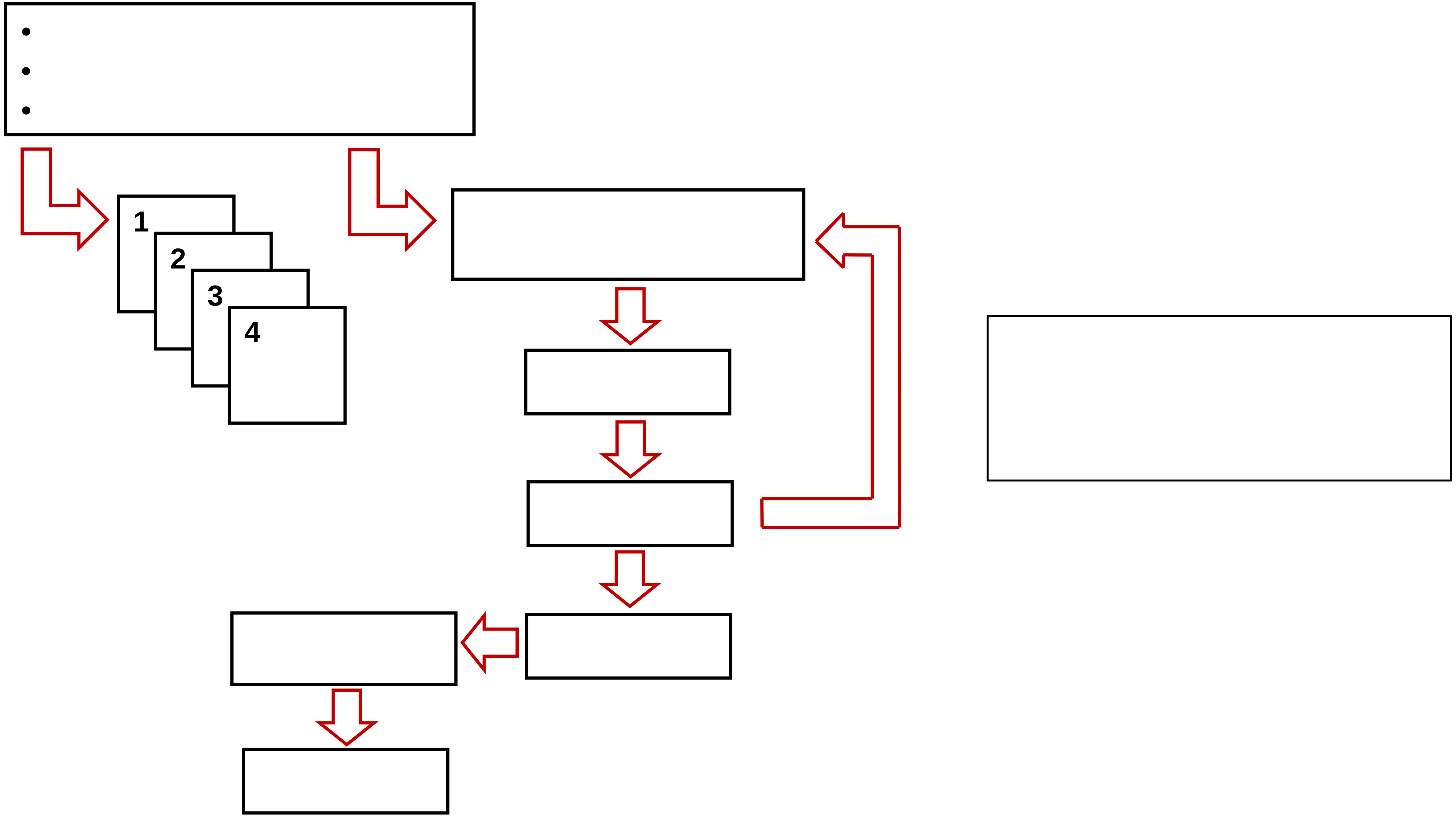
   Resist has either ________________, or better, a _______ shape.

2. Material deposited through the photoresist mask using a _______________________, such as ________________
   - _________________ takes place,
   - Part of the photoresist sidewalls must be free of deposited material
3. Photoresist stripped leaving behind only material deposited through the opening. Unwanted material is __________________________.

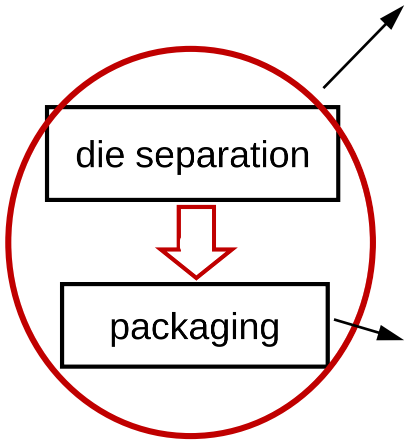
Thickness of the ______________ material must be ______________ compared to the __________ thickness.

Most often used to deposit _______________, especially those that are hard to etch using plasmas

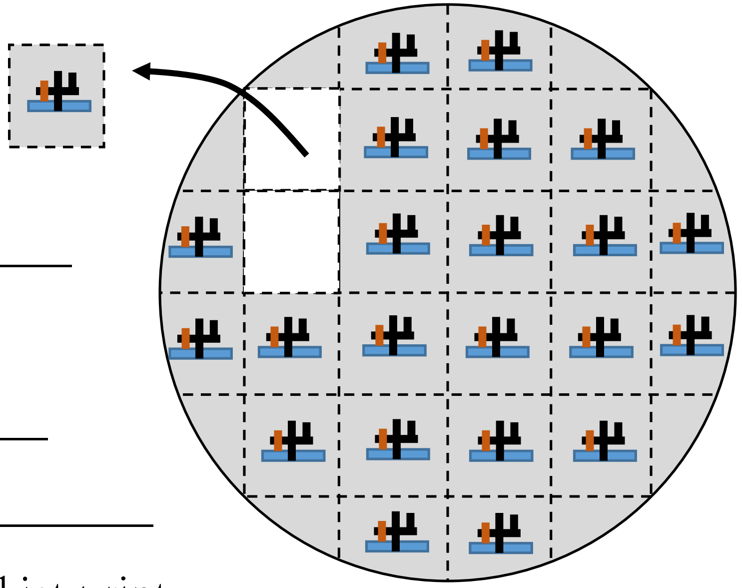
Typical process steps for surface micromachining



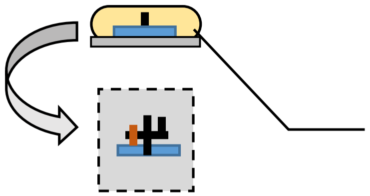
Die separation and packaging



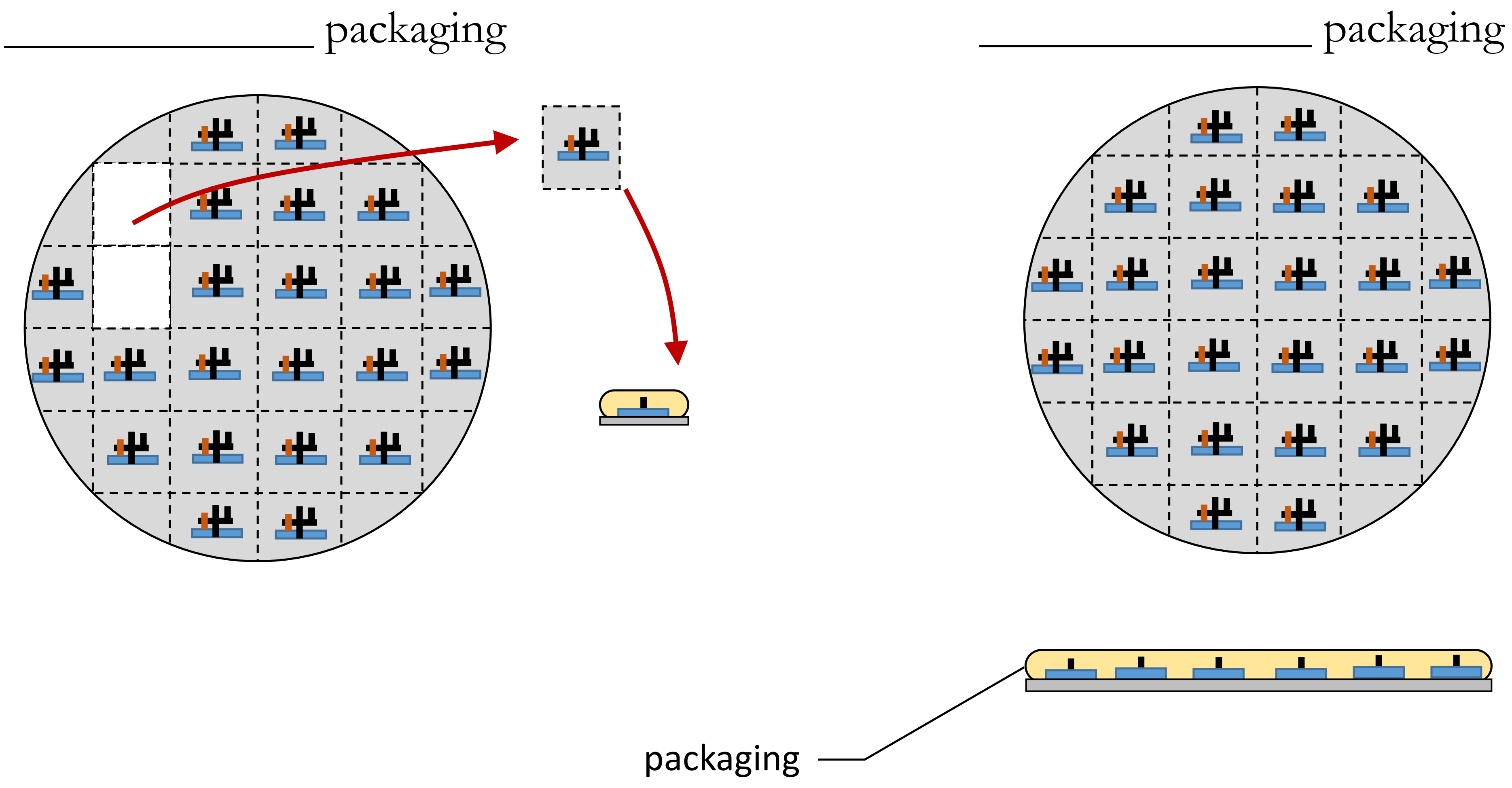
- Must _______________ the individual devices
- Often _______ or _________ the wafer



- Provide MEMS device with ______________ ________________
- __________ MEMS from the ___________
- Sometimes must ____________________________ to environment (e.g., pressure sensor, inkjet print heads)
- Packaging a difficult engineering problem
- ____________________ of producing many (most) devices

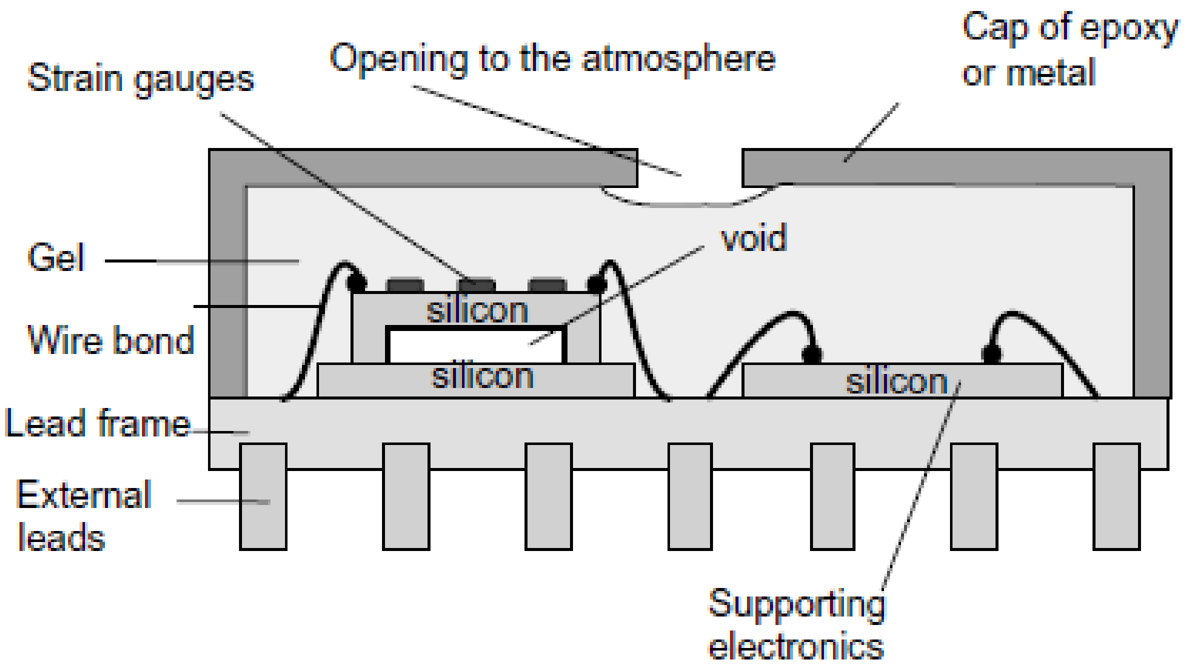


More on packaging



More on packaging

Schematic of a packaged MEMS pressure detector showing some of the requirements unique to MEMS



Process integration (Process flow)

We have learned much about the many materials and techniques for used processing materials to create devices, including

- Nature of crystalline silicon
- Adding material
  - ___________
  - ___________
  - ___________
    - ________
    - ________
- Photolithography
- Bulk Micromachining
- Surface Micromachining

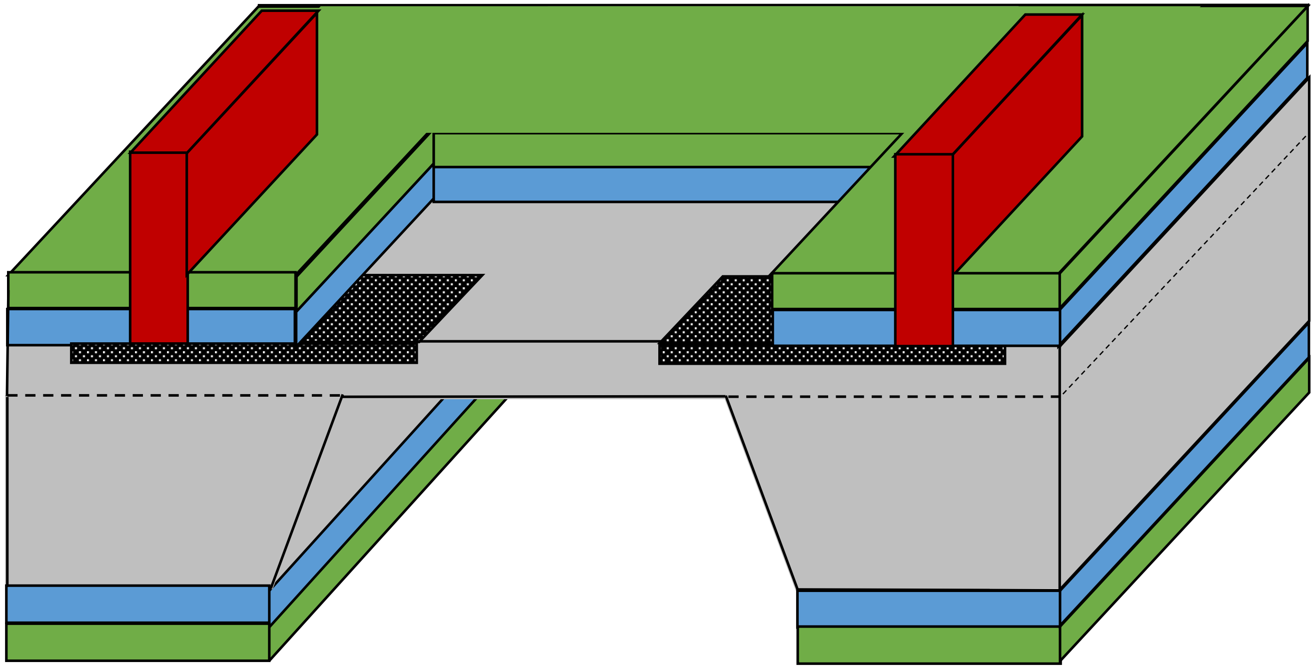
How do we put these things together to create a device?

Specifically:

- ____?
- ____?
- ____
  ____?

Process integration (Process flow)

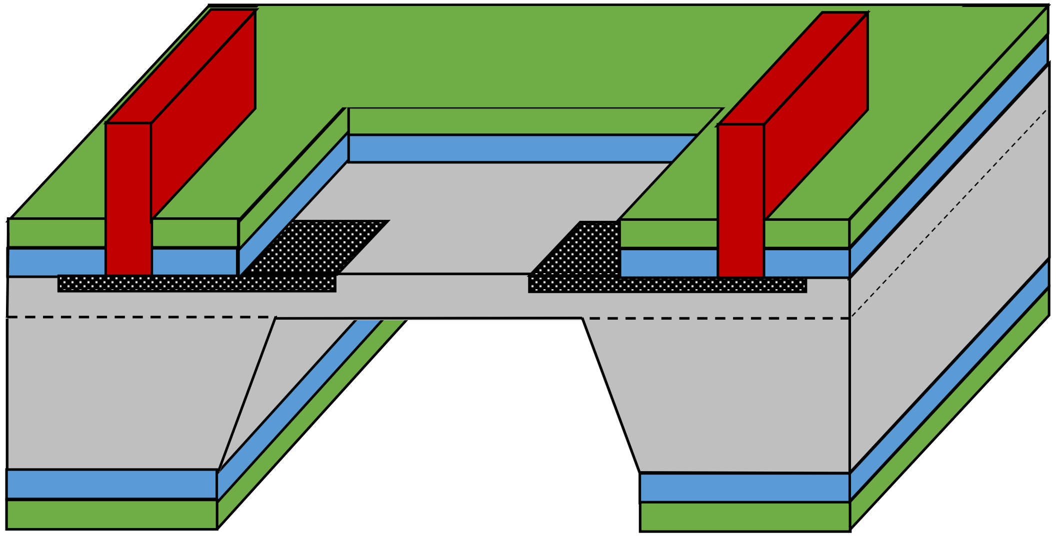
Bulk μ-machined pressure sensor



- Thin Si diaphragm changes shape when pressure changes on one side relative to the other.
- Piezoresistors (implemented using p^+ diffusion) sense the deformation.
- Aluminum wires send resistive electrical signal off the chip.
- n^+ diffusion is used as an etch stop for the backside etch.
- Oxide + Nitride provides wafer protection for backside etch and insulator between Al wires and wafer.

Process flow, pass 1

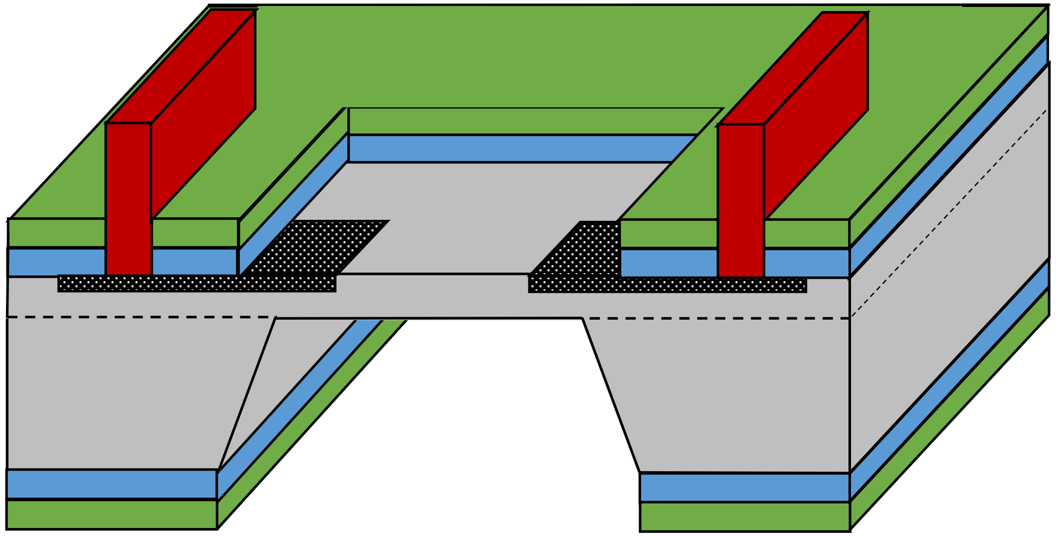
The first pass for determining the process flow is to decide which steps we need.



What are the basic steps necessary to build the **diaphragm**?

Process flow, pass 1

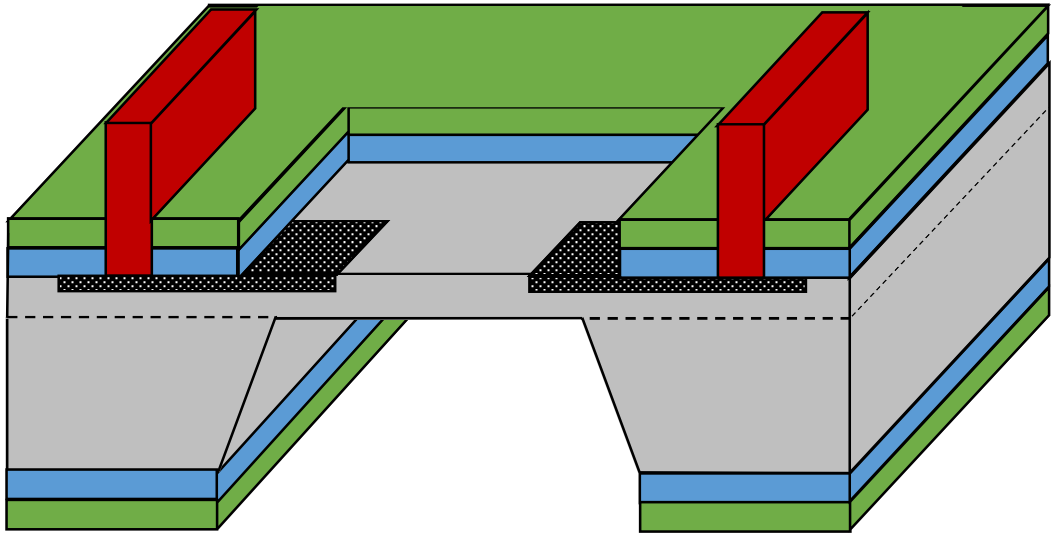
The first pass for determining the process flow is to decide which steps we need.



What are the basic steps necessary to build the **sensor**?

Process flow, pass 1

The first pass for determining the process flow is to decide which steps we need.



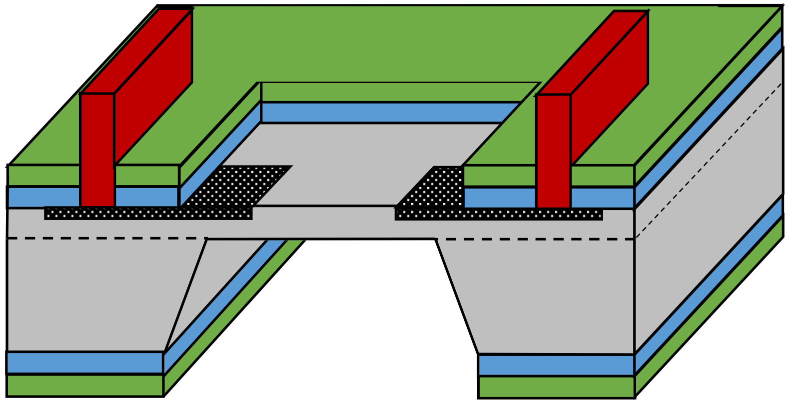
What processing steps are required to produce entire device?

Each of these steps results in more steps in the detailed process flow. But to begin, let's determine the **order** in which the steps must be placed.

Process flow, pass 1

Order of steps

What impacts our decisions on choosing an order?



1. **Geometry**

2. **Temperature**

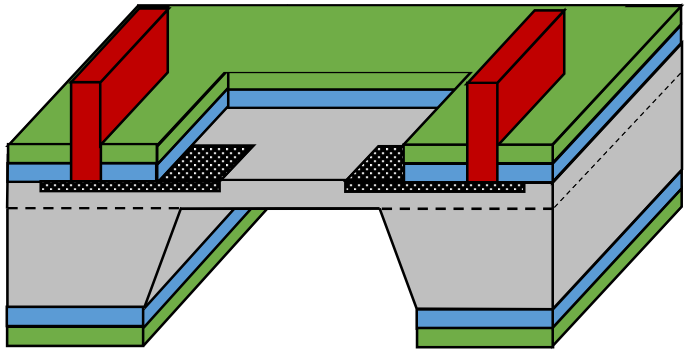
   Which processes are high T?
   - ____________________
   - ____________________
   - ____________________

3. **Mechanical stress**

4. **Interaction of chemicals**

Process flow, pass 1

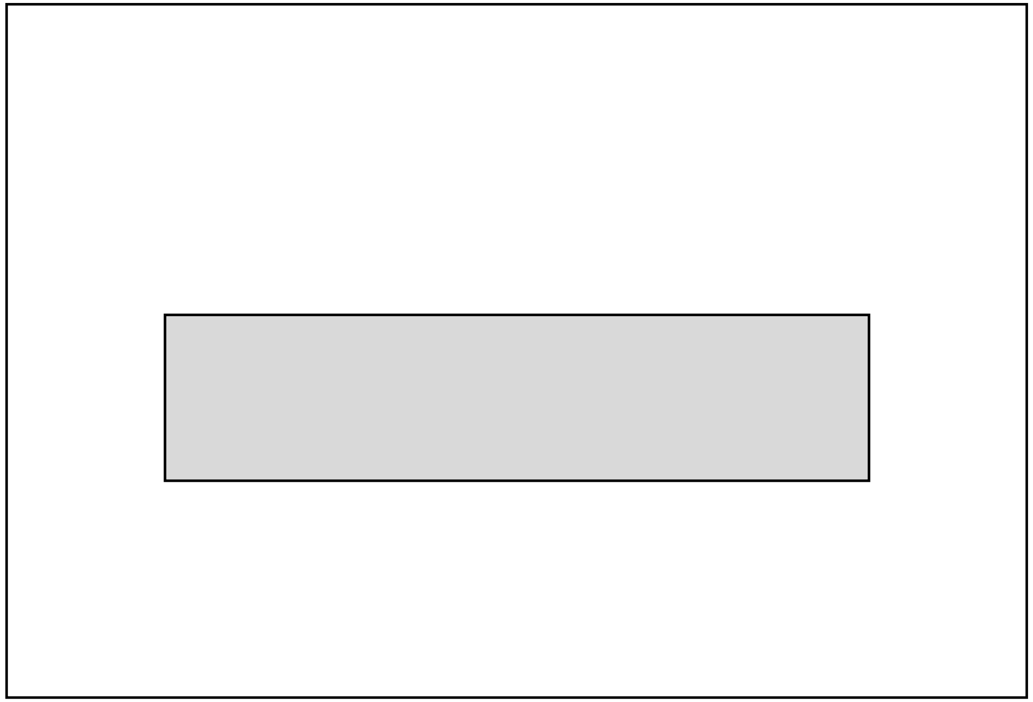
Order of steps



Let’s choose an order

1. ______________
2. _________:

3. ______________
4. ______________



Do we do backside etch or metallization next?

Can we pattern nitride and oxide on both front and back at the same time?

Order of steps

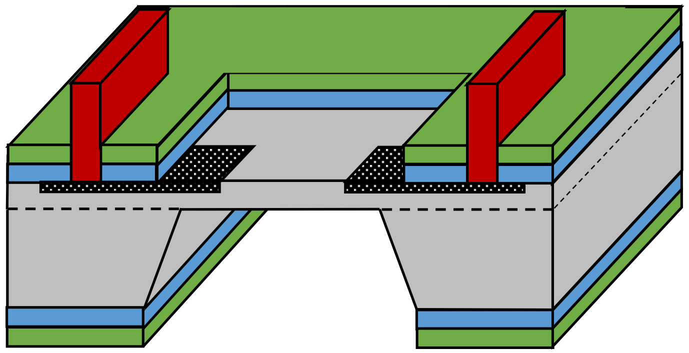
Let's choose an order

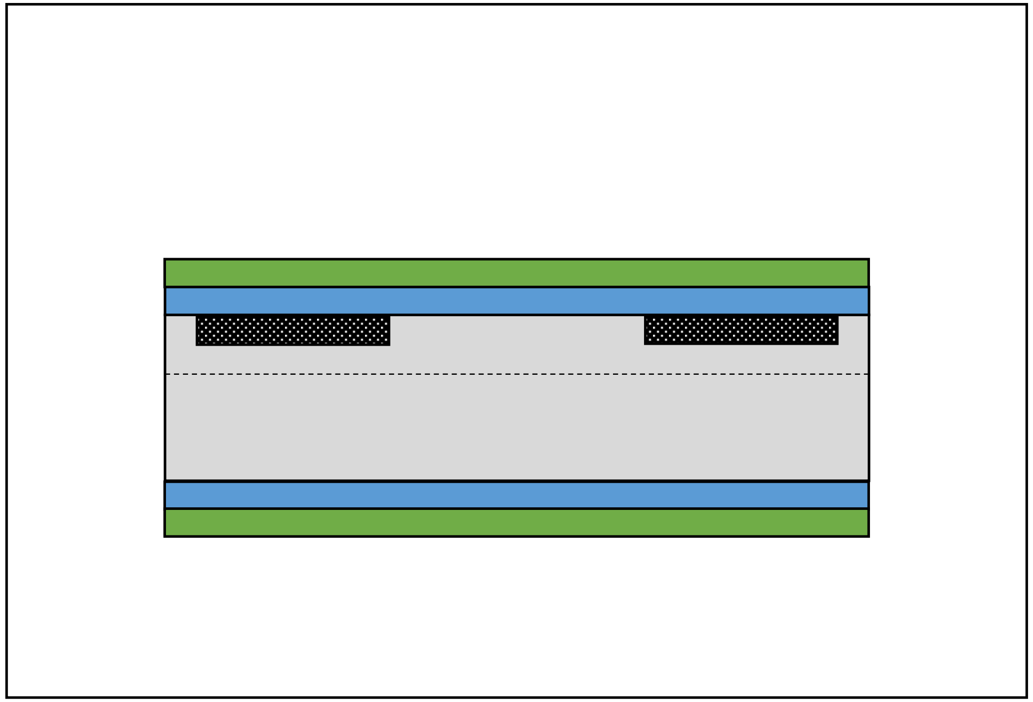
5. ________________:

6. ________________:

7. ________________:

8. ________________:





Pass 2, Detailed process flow

A detailed process flow is the list of all steps necessary for the process people to implement the device. It should include each of the following:

1. All steps in the proper order, including when to clean the wafer
2. Any chemicals necessary
3. Thicknesses of materials

   - These choices come for modeling.
   - The "process people" can turn chemicals and thicknesses into times necessary for etches, depositions, etc.

4. Equipment necessary

   It is the responsibility of the process flow person to think about which equipment is necessary for each step. Why? Because if you need a high temperature deposition to follow a metallization, you need a PECVD to do it or your metal will flow. The process flow person knows the entire process and makes design decisions.

5. MASKS for photoligthography

Detailed process flow

Let's revisit each of the basic steps that we came up with and see what is really involved. You will notice that many of the steps actually turn into several steps when coming up with the detailed process flow. For this exercise, we will **ignore dimensions and chemicals**. However, note that these are also important components of the design flow.

1. n-type doping
   a. Mask?
   b.
      i.
      ii.

2. Oxide
   a. Mask?
   b.

   c.

Detailed process flow

Mask 1

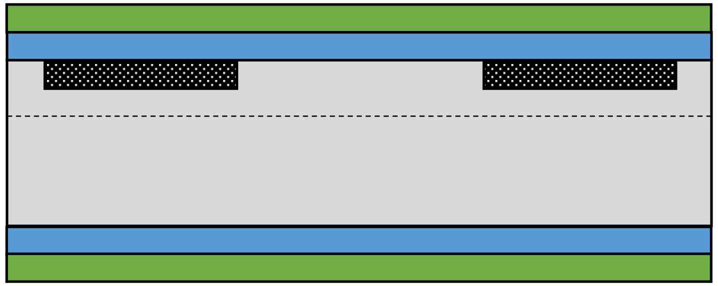
3. Dope resistors and wires
    a. Mask 1 – what does it look like? (Assume positive resist.)
    b. This step requires ___ total steps

4. Deposit nitride
    a. Mask?
    b. Depending on the process, you may need to process ___________ _________ of the wafer.
        i. PVD
        ii. CVD

Detailed process flow

Mask 2

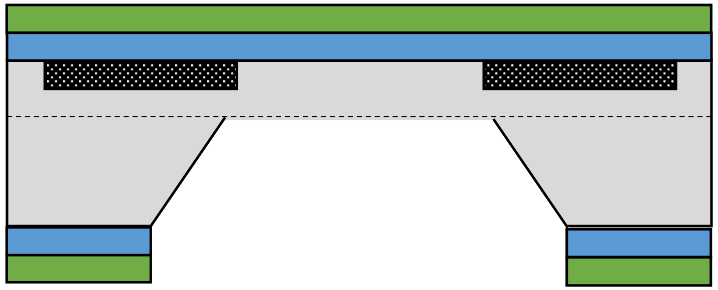
5. Backside etch
   a. Mask 2 – what does it look like? (Assume positive resist.)
   b. Must align Mask 2 with Mask 1 so that ______________________________. → ______________________________
   c. This step requires ___ steps



Detailed process flow

Mask 3

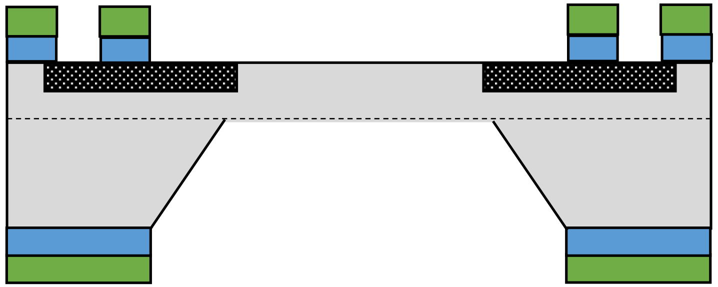
6. Contact Cuts/Diaphragm cut
   a. Mask 3 – what does it look like? (Assume positive resist.)
   b. Must align Mask 3 with ____________ so that wires connect to resistors. →__________ _________
   c. This step requires __ total steps



Detailed process flow

Mask 4

7. Metallization
   a. Mask 4 – what does it look like? (Assume positive resist.)
   b. Must align Mask 4 with ______ so that metal _______ _____________. → *Alignment marks*
   c. This step requires ___ total steps



Pass 3, Final process flow

These steps can be combined to create a **final process flow**.

One additional requirement in process flows is to include information about **when to clean the wafer**. Some general guidelines are:

- Always start with an _______________ and an **HF dip** to get rid of every possible
- All future cleans are usually RCA cleans *without an HF dip*. HF may etch away your MEMS structures.
- *Always* _______________ and ______ before high temperature processes.
- *Always* clean before ______________________.

Final process flow

Final Process Flow for Bulk Micromachined Pressure Sensor

Starting material: 100mm (100) p-type silicon, 1×10^{15} cm^{-3} boron with a 10 mm n-type epilayer, 5×10^{16} cm^{-3} phosphorus

1. **Clean**: Standard RCA clean with HF dip
2. **Oxide**: Grow SiO_2 on both sides of wafer
3. **Photolithography**: Mask 1 (alignment)
   Note: since the first patterned material is diffusion, which you cannot see, you must add alignment marks in the wafer or the first material you can see. If the first patterned material is something you can see, you do not need a separate alignment mark mask.
4. **Etch**: Etch alignment marks into SiO_2.
5. **Strip**: Strip photoresist
   Note: since the next step is not a material deposition or a high temp step, a clean is not necessary.
6. **Photolithography**: Mask 2 (piezoresistors)
7. **Implant**: Ion implantation of boron to achieve 1×10^{19} cm^{-3} at surface after drive-in
8. **Strip**: Strip photoresist
   Note: following step is a high temp step, so must clean wafer before.
9. **Clean**: RCA cleans, no HF dip
10. **Drive-in**: Drive in diffusion to achieve 0.2 μm junction depth
    Note: following step is a material deposition, so must clean wafer before.
11. **Clean**: RCA cleans, no HF dip
12. **Nitride**: Deposit 50 nm silicon nitride using LPCVD
13. **Photolithography**: Mask 3 (backside photolithography for the diaphragm)
14. **Etch**: Remove nitride and oxide from back of wafer
15. **Backside etch**: Etch backside with KOH using electrochemical etch stop
    Note: photoresist strip not necessary since returning to topside of wafer and strip will be done later for topside processing.
16. **Photolithography**: Mask 4 (vias/diaphragm opening)
17. **Etch**: Plasma etch nitride and oxide for vias and diaphragm opening
18. **Strip**: Strip photoresist
19. **Clean**: RCA cleans, no HF dip
20. **Metal**: Deposit 1 μm of aluminum
21. **Photolithography**: Mask 5 (aluminum)
22. **Etch**: Remove Al with PAN etch
23. **Strip**: Strip photoresist
24. **Sinter**: Anneal contacts at 425°C, 30 minutes