Lecture 8/22/24

Introduction to Microfabrication, Continued

Sputtering: low pressure process where accelerated ions, such as Ar, are used to bombard a surface to remove portions of that surface through ablation

RIE: Reactive Ion Etching: uses high speed ions (ex: Ar, SF_6, CF_4) to sputter off material and uses a gas plasma chemistry to convert sputtered material to a gas

- Performed in a vacuum chamber at low pressure
- Popular dry etch technique
- Reasonably high aspect ratio
- Often performed on Si, glass, polymer substrates
    - Solid Si + 4F → SiF_4 (gas)

DRIE: Deep RIE: RIE deep into a substrate

Bosch Process: Iterative vertical RIE followed by a passivation step

- $C_4F_8 + SF_6 \rightarrow CF_2$ (Teflon coating)
- Minimizes lateral etching
- Achieves higher aspect ratio
- Leaves tiny micro-trenches on vertical surfaces

Sacrificial Layer: A temporary layer whose purpose is to create a gap between parts of two other layers

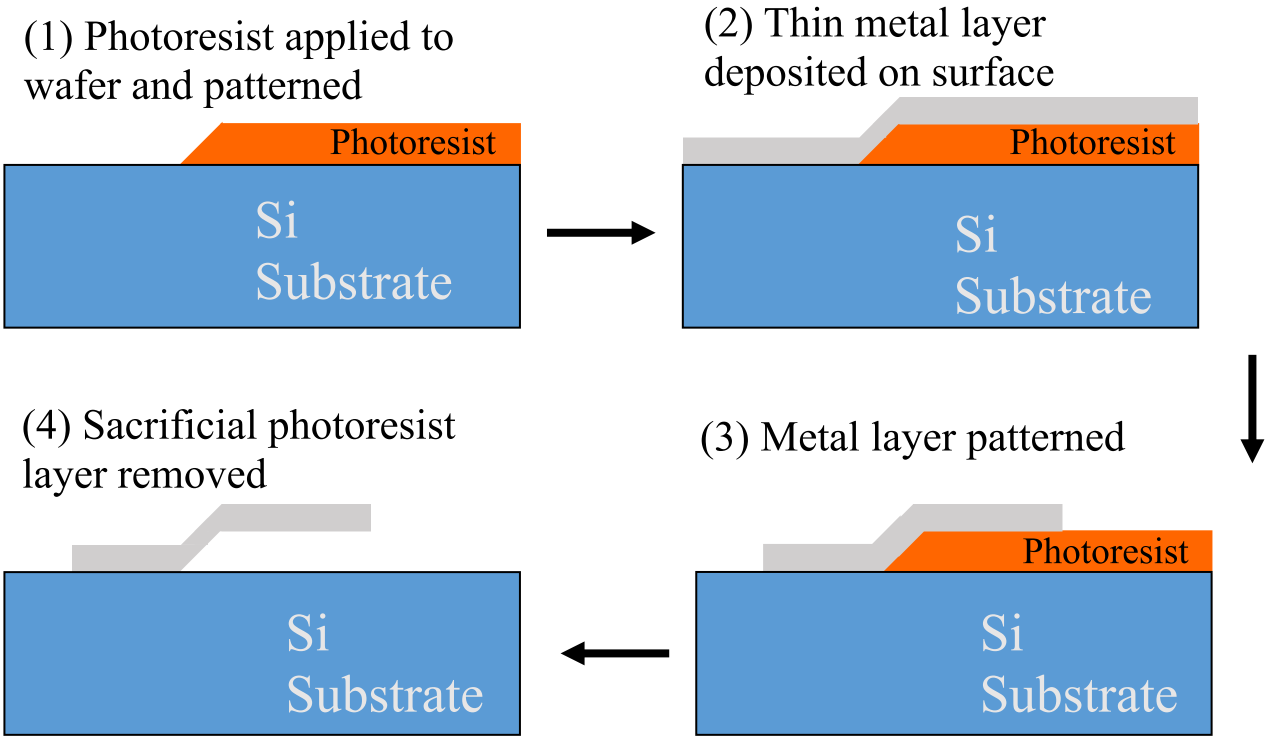
Sacrificial Layer Process

(1) The sacrificial layer is deposited and patterned
(2) The upper layer is deposited and patterned
(3) The sacrificial layer is removed

Release: the process of removing the sacrificial layer that frees a structure to move or deform.

Lecture 8/22/24

Illustration of a Sacrificial Layer Process:


(1) Photoresist applied to wafer and patterned

(2) Thin metal layer deposited on surface

(3) Metal layer patterned

(4) Sacrificial photoresist layer removed

Stiction: "Static Friction", when two micro-structures come into contact, they tend to stick together

Due to several forces acting on small masses:

(1) Electrostatic forces between charged surfaces
(2) Capillary forces from a high surface tension during a wet etch release can pull micro-structures together, that are then held together by Van der Waals forces
(3) Spot welding

Stiction is a MAJOR problem in MEMS devices

Stiction often occurs when using a liquid etchant to remove a sacrificial layer: capillary forces can pull micro-structures into contact as the liquid dries. TPD and CPD are sometimes used to mitigate this issue.

Triple Point Drying: (TPD) a drying process to avoid stiction by going from liquid to solid to gas, avoiding stiction problems due to surface tension from going from liquid directly to gas.

Critical Point Drying: (CPD) a drying process to avoid stiction by going from liquid to supercritical liquid to gas. Supercritical liquid to gas has almost no surface tension.

TPD or CPD is performed in a special temp/pressure chamber

Example TPD Process

(1) Liquid etchant is replaced with liquid water
(2) Water is frozen: ice
(3) Ice is sublimated (solid directly to gas)

Example CPD Process

(1) Liquid etchant is replaced with alcohol
(2) Alcohol is replaced with liquid CO_2
(3) Liquid CO_2 to supercritical CO_2
(4) Supercritical CO_2 to gaseous CO_2
(5) Replace CO_2 with atmospheric gases

Both TPD and CPD are fairly harsh processes that can damage fragile microstructures.

Lecture 8/22/24

Dicing: The process of cutting wafers into individual die (singulation)

Uses an automated diamond saw and water jet cooling

Care must be taken to protect fragile micromachined structures during dicing

The final release etch is usually done after dicing to protect fragile structures and to prevent stiction from the water

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Thin Film Metallization: Sputtering and Electron Beam Deposition

Sputtering Deposition: Sputtering is used to remove atoms from a sputtering target, which migrate across a low-pressure chamber and deposit on a substrate.

E-Beam Deposition: A focused electron beam is used to evaporate material from a target, which migrates across a low-pressure chamber and deposits on a substrate

Typically 2 or 3 layers deposited:

(1) Adhesion layer, Ti or Cr
(2) A barrier layer, Ni
(3) A top layer, Au

Wire Bonding: The process of attaching tiny wires between pads on the die and pads on the package the die is attached to/in

Typical wire bonding wire: 25µm diameter Au wire

Al, Ti-Au, Ti-Ni-Au “can be” wire bonded

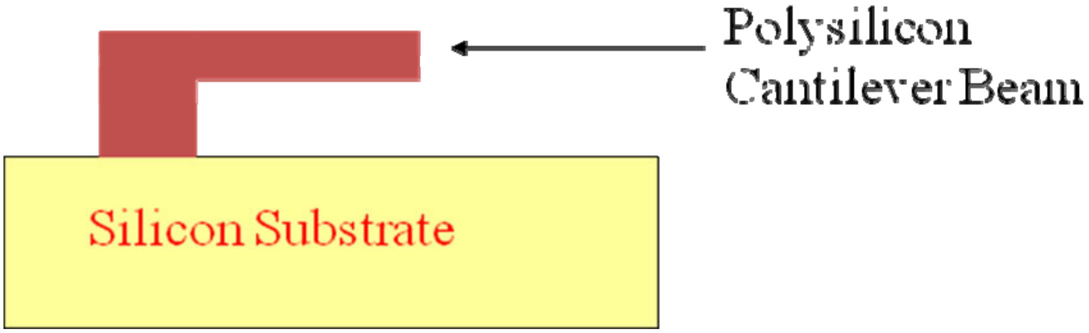
Ti-Ni-Au “can be” soldered

Lecture 8/22/24

Surface Micromachining: The addition and subtraction of layers of materials on top of the substrate to realize a micromachined device

Example materials: metal films, polysilicon, polyimide, epoxies (SU-8)

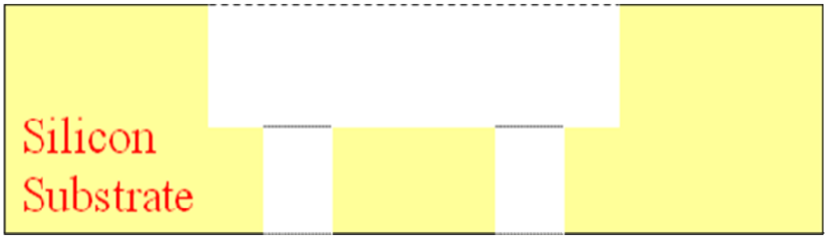
Example:



Bulk Micromachining: Removal of the substrate material to realize a micromachined device

Example processes used: DRIE, wet etching

Example:



<u>Wafer Bonding</u>: The process of permanently attaching 2 wafers together

<u>Wafer Bonding Processes</u>:

(1) Gluing or adhesive bonding
(2) Eutectic bonding: solder
(3) Anodic bonding: Si to a special glass
(4) Si fusion bonding: high temp Si-Si bonding

Useful for fabricating complex MEMS devices

<u>SOI Wafers</u>

<u>SOI</u>: Silicon On Insulator: A type of wafer often used in making MEMS devices

SOI wafers consist of three layers

(1) A thick silicon base <Handle Layer> - Bottom Layer
(2) A thin silicon dioxide layer <Box Layer> - Middle Layer
(3) A thin silicon layer <Device Layer> - Top Layer

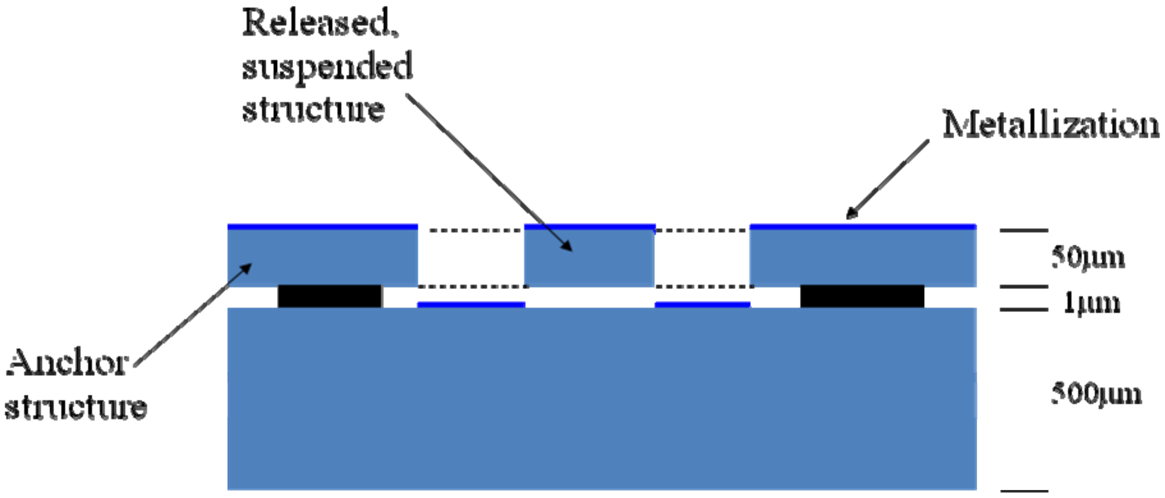
For MEMS applications: SOI wafers are manufactured by wafer bonding 2 wafers together and grinding and polishing one of them back to the desired Device Layer thickness

<u>SOI Wafer Illustration</u>

Typical SOI MEMS Fabrication Process

1. Photolithography on the device layer and Bosch process DRIE down to Box layer
2. Dice wafer into individual die
3. Remove most of the Box layer with timed liquid or vapor HF acid
4. Replace liquid HF acid with alcohol solution
5. Critical/triple point drying (liquid HF process only)
6. Thin film metallization (Al, Ti-Au, Ti-Ni-Au)
7. Mount in package and wire bond

Example SOI MEMS Device (cross-sectional view):



Polysilicon on Si Process

Alternative to SOI process

1. Grow thin (≤1µm) SiO_2 layer on the Si wafer
2. Grow thin (≤5µm) polysilicon layer on the SiO_2 layer
3. Pattern the polysilicon layer like the Device Layer in the SOI process
4. Similar to rest of SOI process…

Note: the SOI Device Layer can be much thicker than the polysilicon layer and has some different material properties

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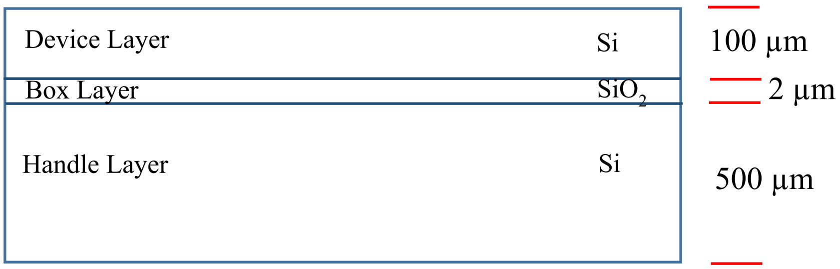
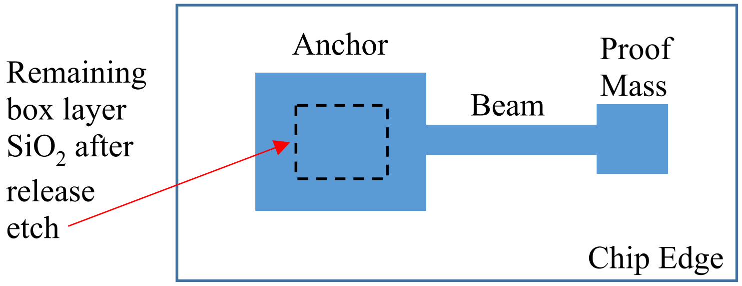
Realizing a MEMS Device with an SOI wafer

SOI wafer:

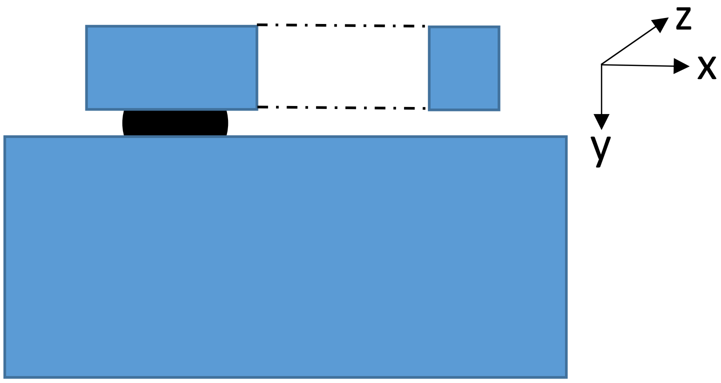


Example simple MEMS device in SOI process:

Top down view



Cross-sectional view



Lecture 8/22/24

Anchor (rigid structure): does not bend/deform when subjected to external forces

Proof Mass (rigid structure)

Beam (flexible or elastic structure) does bend/deform when subjected to external forces. It will return to its original shape when those external forces are removed: it undergoes elastic deformation.

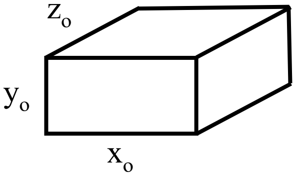
Beam ≡ Spring ≡ Flexure

Silicon (Si) is our primary structural material

Si material properties:
Density: $\delta = 2.3$ g/cm^3
Young's Modulus: E = ~165 GPa {111 to 190 GPa, type of Si and crystal plane dependent}
(note: 1 Pa = 1 N/m^2)

E ≡ stress/strain

Proof Mass



Volume = $V = x_o y_o z_o$

Mass = $m = \delta V$, $[m] = kg$

Note: Be careful of unit conversions: μm to m, etc.

Associated with mass in inertial force, F_I

$F_I = ma$

Homework 1