Lecture 8/19/22

Introduction to Microfabrication

Fabrication processes used to fabricate integrated circuits and most MEMS devices

For a more detailed study of microfabrication:

(1) ELEC 5730/6730 Microelectronic Fabrication

(2) ELEC 5820/6820 MEMS

Micromachining: A term used to describe the process of fabricating MEMS or micromachined devices

Silicon (Si)

The base material for microfabrication: Substrate

Si is the most common substrate material

Si: hard, brittle semiconductor material

Single crystal Si is grown into ingots and sawn/polished to produce thin wafers – used as substrates

(1) Example Si wafer: 100mm diameter and 500μm thick
(2) Diamond crystal structure, different crystalline planes: (100), (110), (111): with different properties
(3) Can be doped n- or p-type: can be high or low resistivity

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Other Materials in Si Based MEMS:

(1) **SiO_2**: grown onto exposed Si though a process called oxidation
  Typically less than 1µm thick
(2) **Polysilicon**: polycrystalline Si deposited onto a substrate
  Up to a few µm thick
(3) **Metallization**: deposited layers or "films" of metal (Al, Ti, Au, Cr…)
  Thin films: up to few µm thick
  Thick films: greater thicknesses (up to 100s of µm thick)
(4) **Non-metallic layers:**
  Silicon nitride (SiN)
  Various polymers
  Diamond coatings
  Epoxies

Materials in Non-Si Based MEMS:

(1) SiC (silicon carbide)
(2) Diamond
(3) Glasses
(4) Ceramics
(5) Polymers / plastics
(6) PCB laminates
(7) Metals
(8) 3D printed materials

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2 Basic Processing Types:

(1) **Additive Process:** The deposition of a layer or volume of a material

(2) **Subtractive Process:** The removal of some amount of a material

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Basic Microfabrication Processing Terms

Patterning: The process of transferring a designed pattern into a physical layer

Photolithography: A process of patterning a light-sensitive organic layer called photoresist (PR)

Photolithography mask: a transparent glass plate with an opaque pattern (plated Cr) on one side that the designer desires to transfer to the substrate or thin layer

Photolithography Process

(1) Clean wafer
(2) Spin coat on a uniform layer of PR
(3) "Soft bake" to dry the PR
(4) Align the photolithography mask to the wafer and place it in contact with the PR layer – using a mask aligner
(5) Expose it to UV light for a set time (only areas not covered by the Cr pattern are exposed
(6) Develop the PR in a liquid developer
    Exposed PR removed – "positive PR"
    Unexposed PR removed – "negative PR"
(7) "Hard Bake" to harden the remaining PR

After Photolithography

(1) Affect the exposed layer beneath the PR
(2) Remove the remaining PR (solvents, O_2 plasma "ashing")

Etching: the selective removal of a material

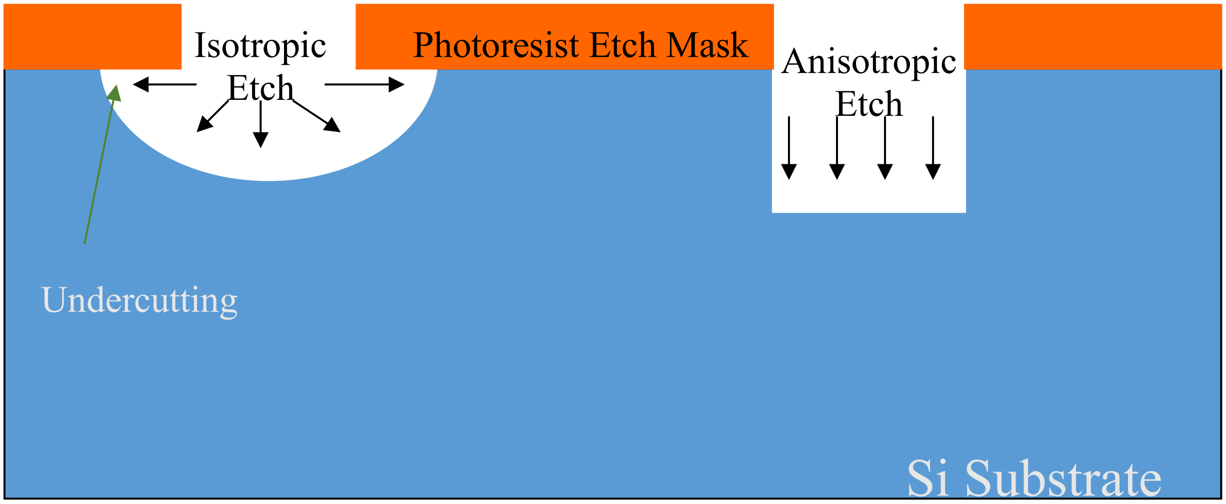
Selectivity: The properties of an etchant with regard to what it will and will not etch. Typically want a high selectivity.

PR Etch Mask: A patterned layer of PR used to only expose some areas for etching

Isotropic Etch: Equal etching effect in all directions

Anisotropic Etch: Unequal etching effect in different directions

Undercutting: Where the etch process undercuts the PR or other etch mask



There are no purely anisotropic etch processes.

Aspect Ratio: Ratio of depth to width of an etched feature.
Example: 10:1 - 10µm down, 1µm over

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

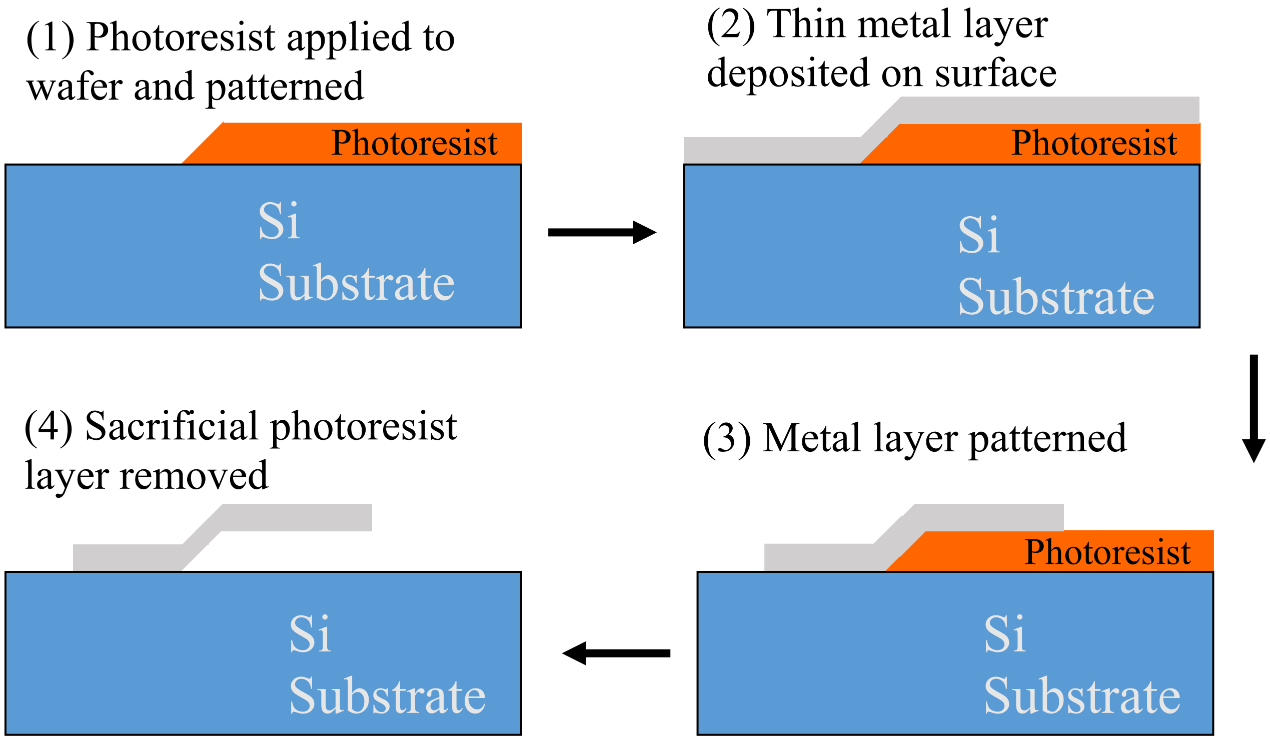
Sacrificial Layer: A temporary layer whose purpose is to create a gap between parts of two other layers

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.

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.

Dicing: A process by which wafers are cut into individual die

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