EE 701: Introduction to MEMS

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Thin-film deposition and growth

- Physical Vapor Deposition
  - Evaporation
  - Sputtering

- Chemical Vapor Deposition

- Electroplating

- Atomic Layer Deposition

- Thermal oxidation

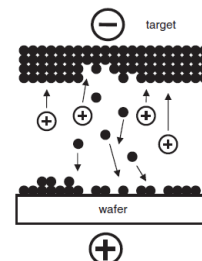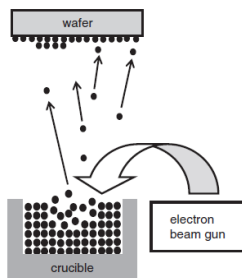- Epitaxial growth including MBE

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Physical Vapor Deposition

- Atoms ejected from a solid target using a number of different methods (resistive heating, electron beam heating, ion bombardment, etc.)

- There are two main methods:
  - Evaporation
  - Sputtering

- Evaporation: Metal sample is heated (e.g. using an electron beam) and the resulting flux of vapor atoms is deposited onto a wafer under vacuum.

- Sputtering: Chemically inert atoms (such as Ar) are ionized in a glow discharge and accelerated into the target. Atoms from the target are physically knocked out and deposited onto a wafer under vacuum conditions.

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Physical Vapor Deposition

- Evaporation: Used for metals such as Au, Al (low melting point). Deposition rates are typically quite low but film quality is good.

- Sputtering: Used for metals, dielectric films (such as SiO2), and some specialty films such as ZnO, AlN. Deposition rates can be quite high but less directional than evaporation.

S. Franssila, Introduction to microfabrication, John Wiley & Sons, 2nd edition, 2010.

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Adhesion of thin films

- Adhesion of films to surfaces is a major issue. This can depend on a number of factors including the chemical nature of the surface and the deposited film, surface cleanliness, nature of process employed.

- Adhesion layers are additional layers used to improve adhesion to surfaces. Typically, these are very thin layers (~10nm) deposited on the surface ahead of the primary film within the same deposition system.

- Cr, Ti are good adhesion layers for metals based on their bond forming abilities.

- Combination of adhesion layers / noble metals include Cr/Au and Ti/Pt.

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Chemical Vapor Deposition

- Precursor materials are introduced into a heated furnace housing the wafers. A chemical reaction occurs on the surface of the wafer leading to film growth while the by-products of the reaction are extracted away from the surface.

- A variety of thin-film materials can be deposited including silicon nitride (reaction of dichlorosilane and ammonia), silicon dioxide (silane or silane derivative with a suitable oxidizing species such as oxygen or nitrous oxide), polysilicon (decomposition of silane), etc.

- Typically, deposition is carried out a high temperatures (500-850 ^{o}C) in vacuum (< 1 Torr pressure). Acronym LPCVD is used to identify low-pressure CVD processes.
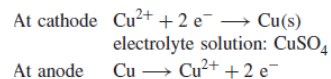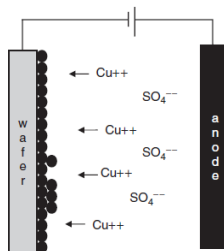
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Chemical Vapor Deposition

- If deposition occurs on a single-crystal silicon substrate it is possible for the underlying crystal to serve as a template for the deposited film and extend the single-crystal. This is known as epitaxy. It is widely used for silicon. This process is associated with slower deposition rates while polycrystalline silicon (polysilicon) deposition is associated with higher deposition rates.
- Deposition rates can be enhanced if the deposition occurs in a glow discharge plasma. This type of deposition is referred to as PECVD (plasma-enhanced CVD). This can be used to deposit dielectric films at lower temperatures (< 400 °C).
- Apart from epitaxy, films deposited by LPCVD are either amorphous (inorganic dielectrics) or polycrystalline (polysilicon or metals).
- Material properties can depend on the exact process including temperature, gas flow rates, pressures, underlying film).

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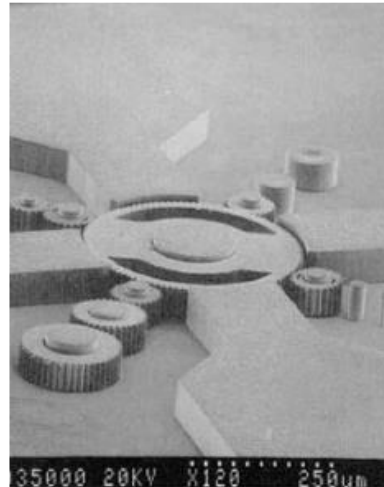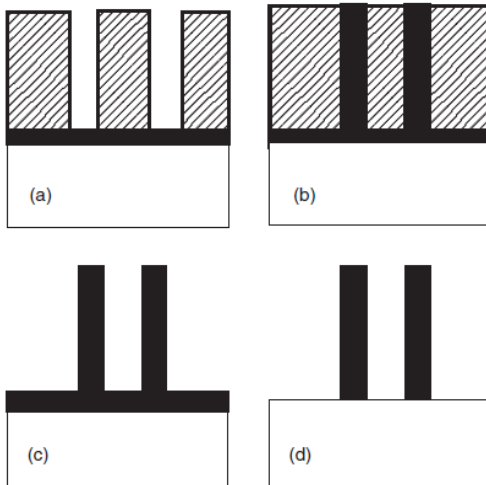# Electroplating / Electrodeposition

- Electrochemical process where metal ions in solution are deposited onto a substrate.
- Well suited to metals such as Au, Cu, Cr, Ni, and Ni-Fe alloys.
- Can result in relatively thick films and rougher films relative to evaporated or sputtered films.

At cathode $Cu^{2+} + 2\ e^- \longrightarrow Cu(s)$
electrolyte solution: $CuSO_4$
At anode $Cu \longrightarrow Cu^{2+} + 2\ e^-$

S. Franssila, Introduction to microfabrication, John Wiley & Sons, 2nd edition, 2010.
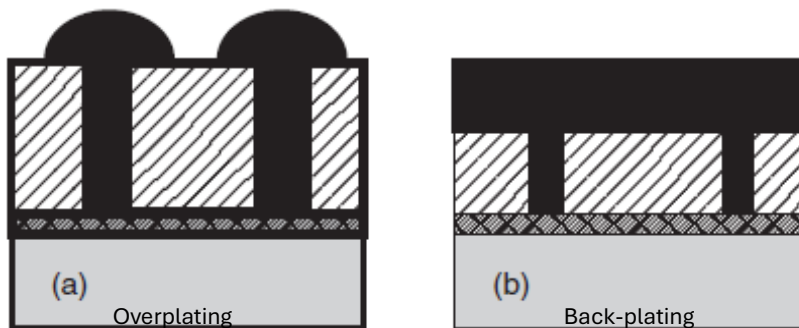
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LIGA process based on electroplating

(a) – Seed layer deposition and resist patterning, (b) – Plating of metal, (c) – Removal of resist, (d) – Removal of seed layer
S. Franssila, Introduction to microfabrication, John Wiley & Sons, 2nd edition, 2010.

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Back-plating and Overplating
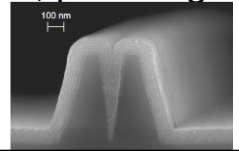

(a) Overplating

(b) Back-plating

- In overplating, mushroom-like structures can be created which can be annealed to form bumps for flip-chip bonding.
- In back-plating, resist removal can allow for the creation of air bridges using metal or closed microfluidic channels.

S. Franssila, Introduction to microfabrication, John Wiley & Sons, 2nd edition, 2010.

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Atomic layer deposition (ALD)

- Films are deposited one atomic layer at a time.
- First precursor molecules are brought to the surface resulting in a reaction and occupation of all possible binding sites.
- This is then followed by a purge (e.g. with nitrogen) to remove unreacted precursor molecules.
- Then the second precursor molecules are brought to the surface resulting in a reaction with the first layer. The unreacted molecules are extracted.
- Deposition rates are very low but quality of films are good, providing high step coverage.
- Used in thin coatings of metals and dielectrics.

S. Franssila, Introduction to microfabrication, John Wiley & Sons, 2nd edition, 2010.

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Oxidation of silicon

- High quality oxide can be grown thermally on the surface

- Carried out in furnaces at temperatures from 850-1150 ^{o}C.

- Dry oxidation: Pure oxygen is used, flowed through the furnace with nitrogen as a diluent.

$$Si + O_2 \rightarrow SiO_2$$

- Wet oxidation: Steam is used instead of dry oxygen.

$$Si + 2H_2O \rightarrow SiO_2 + 2H_2$$

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Kinetics of oxide growth

- Modelled by the so-called "Deal-Grove" model.

- Initial rapid oxidation of the surface followed by a slowing down due to diffusion of oxygen molecules through grown oxide.

- Some of the silicon is consumed in the process – so the added thickness is 54 (added thickness of SiO_2): 46 (consumed silicon)

Si	SiO_2
	Si
	SiO_2

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Kinetics of oxide growth

- The oxide thickness (> 30 nm) can be given by the expression:

Final thickness $\quad x_f = 0.5 A_{DG} \left[\sqrt{1 + \frac{4 B_{DG}}{A_{DG}^2}(t + \tau_{DG})} - 1 \right]$

$$\tau_{DG} = \frac{x_i^2}{B_{DG}} + \frac{x_i}{(B_{DG}/A_{DG})} \quad \text{Initial thickness}$$

Temperature dependent constants

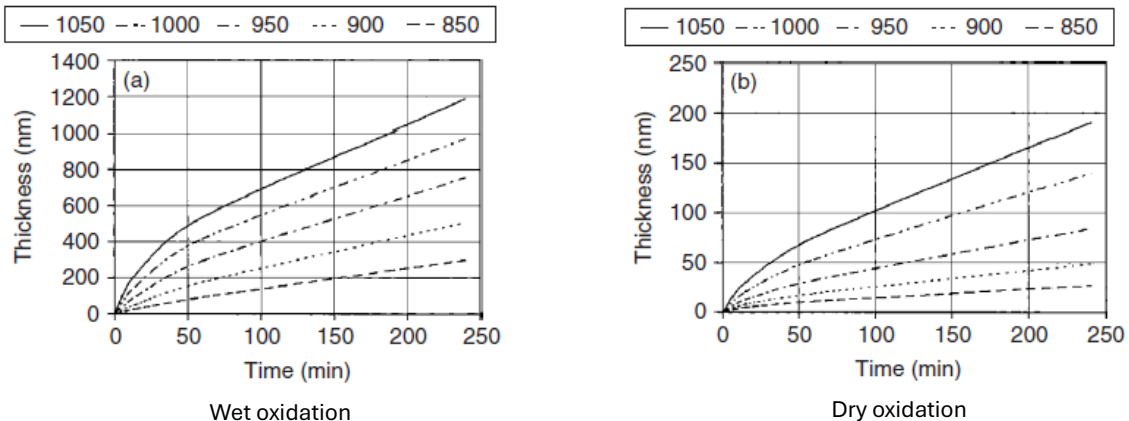- For small times this is simplified as:

$$x_f = \frac{B_{DG}}{A_{DG}}(t + \tau_{DG})$$

- For long times this is written as:

$$x_f = \sqrt{B_{DG} t}$$

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Visualizing the growth of wet and dry oxides

Wet oxidation

Dry oxidation

S. Franssila, Introduction to microfabrication, John Wiley & Sons, 2nd edition, 2010.

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Spin-casting

- Thin films deposited from solution (typically a polymer or chemical precursor to a polymer).
- Solution is applied to a wafer and the wafer is spun at high speed. Centrifugal forces, in combination with surface tension and viscosity of the solution result in the film being spread to a uniform thickness.
- After spinning, baking in an oven is used to remove the remaining solvent (and perform any chemical reactions).
- Used for depositing photoresist, polyimide films (insulating polymers which can withstand temperatures to about 400 $^{\circ}$C).

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