EE669
Thin Film Deposition

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Outline

- Introduction
- Physical Vapor Deposition (PVD)
  - Conceptual system
  - Evaporation
  - Film growth processes
  - Sputter deposition
- Chemical Vapor Deposition (CVD)
  - Thermal CVD
  - CVD kinetics
  - Plasma enhanced CVD (PECVD)
- Atomic Layer Deposition (ALD)

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Types of thin film processes

- Physical vapor deposition
  - Source: atleast one solid which is evaporated or sputtered
  - The material vapor *condenses* on the substrate to form the film
  - Examples: thermal evaporation of metals, e-beam evaporation, pulsed laser deposition, physical sputtering, MBE, ….
- Chemical vapor deposition
  - Source: fluid (gases and liquids)
  - Chemical reaction between sources (reactants) on the target surface
  - Examples: thermal CVD, APCVD, low pressure CVD, high pressure CVD, HW-CVD, plasma enhanced (assisted) CVD, photon assisted CVD, e-beam assisted CVD, Ion beam assisted CVD, ALD, PE-ALD,….

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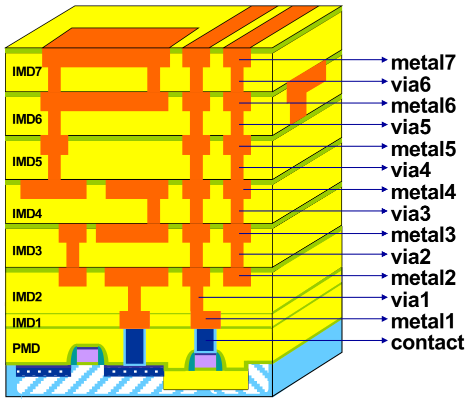
Thin film processes: importance in VLSI



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Thin film processes: importance in VLSI

Exercise: List out the thin film materials deposited in the CMOS process (SiO2/poly-Si gate) upto and including first level of copper. See your lecture notes on the lectures on CMOS integration. Also state the method used for the deposition of each of these processes.

PVD and CVD: Some Comparisons

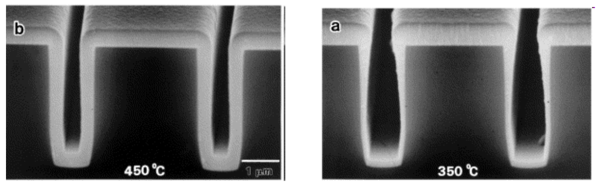
- **PVD:**
  - **Requires targets (sputter) or charges (evaporation) of the material to be deposited**
  - **High purity targets are easy to get and handle**
  - **High purity materials can be deposited**
- **CVD:**
  - **The reactants (precursors) can be in gaseous, liquid or solid form**
  - **Precursors should have sufficiently high vapor pressure (~1 mbar at RT)**
  - **Precursor should be sufficiently pure**
  - **Film contaminated with precursor components and reaction by-products**
  - **New thin film material means synthesis of appropriate precursors**
  - **Many precursors are not easy to handle as they can be poisonous, inflammable, corrosive,…….**

Thin film properties

- **Physical and chemical**
  - **Chemical composition**
  - **Thickness**
  - **Refractive index and optical absorption**
  - **Film density and porosity**
  - **Contaminants incorporated in the film**
  - **Defect (particle, voids, pin-holes,….) density**
  - **Step coverage**

Thin film properties (2)

- **step coverage**

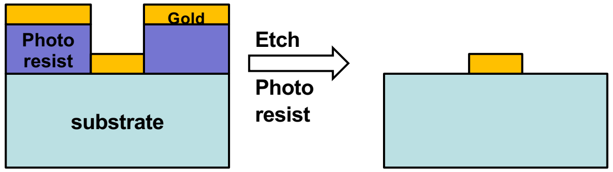


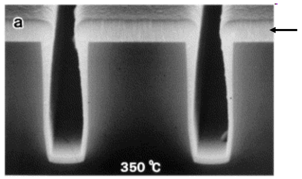
Ohshita et al., Thin Solid Films, 1 March 2002, pp. 215

- **Step coverage (%) = 100 * thickness on the sidewall/thickness on the top**
- **Depends on the process type and aspect ratio**
- **Thermal CVD ~ 100%**
- **PECVD: controllable, < 100%**
- **PVD < 100% (MBE and thermal evaporation ~ 0%)**
- **ALD ~ 100%**

Applications and implications of step coverage

Lift off process





If this is a metal

Thin film properties (3)

* Electrical
  - Metals:
    - Conductivity
    - Robustness against electro migration
  - Semiconductors:
    - Controlled conductivity, doping
    - Low density of generation/recombination centers
    - Low density of stacking faults, twins etc (low junction leakage)
    - Controlled stress/strain
  - Dielectrics
    - Good insulating properties
    - High breakdown fields
    - Low density of charge traps and pin holes
    - Dielectric constant
  - High quality interfaces between materials

Thin film properties (4)

- All properties are influenced by the growth conditions
  - Metals: high conductivity & robustness against electro migration
    - Large grain size results in lower sheet resistance for metal films. Grain size depends on process temperature…..
  - Semiconductors:
    - Low density of generation/recombination centers: influenced by the growth rate, temperature, presence of impurities in the precursor, ….
    - Crystalline phase: amorphous versus nano/micro crystalline versus poly crystalline versus monocrystalline: influenced by process temperature, plasma power etc.

Thin film properties (5)

Comparison of deposition techniques

Method =>	PLD	MBE	Evaporation	Sputtering	ALD	CVD
T uniformity	poor	fair	fair	good	good	good
Sharp Interface	varies	good	good	poor	good	fair
smooth interface	varies	good	good	varies	good	varies
sharp dopant profile	varies	good	good	poor	good	fair
step coverage	poor	poor	poor	poor	good	varies
Deposition rate	good	fair	good	good	poor	good
Vacuum	high	ultra high	high	high	varies	varies
Indistrial applications	poor	varies	good	good	varies	good

High vacuum: 10^{-1} to 10^{-7} Pa; Ultra high vacuum: 10^{-7} to 10^{-10} Pa

Adapted from Jill Becker, Ph. D. thesis, MIT, 2002