EE 527 MICROFABRICATION

Lecture 10

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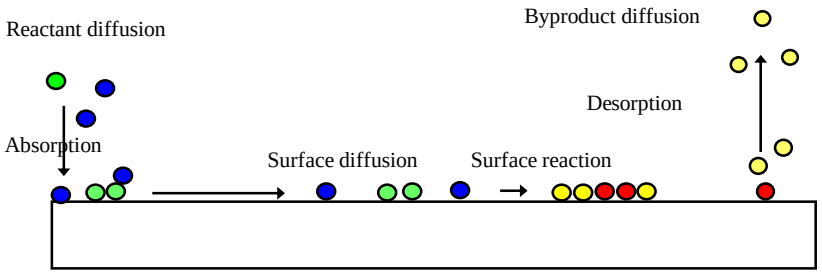
CHEMICAL VAPOR DEPOSITION (CVD)

- Chemical vapor deposition:
  - Transport of reactant species into the reactor : the source materials are brought into the reactor in the gas phase.
  - Diffuse to the substrate surface
  - React to deposit film at substrate surface
  - Desorbed and pump away the reaction by-products
- Three major techniques of CVD:
  - APCVD: atmospheric pressure
  - LPCVD: low pressure
  - PECVD: plasma enhanced

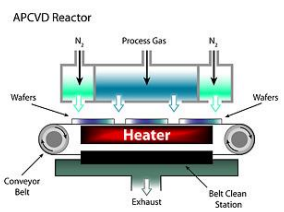
CVD/CVD PROCESS FLOW



Three major CVD Techniques

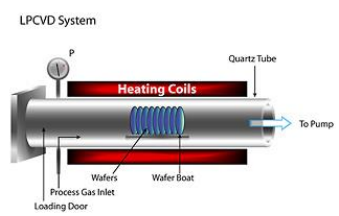
- APCVD: atmospheric pressure (mass-transport-limited)
- LPCVD: low pressure (surface-reaction-limited)
- PECVD: plasma enhanced (mass-transport-limited)

CVD/LPCVD AND APCVD EQUIPMENT



(a) APCVD inline furnace

- continuous throughput
- atmospheric pressure
- reactants contained by gas curtains
- fast gas flows
- frequent clean cycles



(b) LPCVD quartz tube batch furnace

- low pressure (0.25 - 5 torr)
- up to 200 wafers
- good uniformity

http://www.dowcorning.com/content/etronics/etronicschem etronics_newcvd_tutorial3.asp

CVD/CVD PROPERTIES

General CVD

- Films are generally less dense, include hydrogen
- Higher etch rates
- Films usually under tensile stress
- Films are quite conformal

Plasma enhanced CVD

- Some sputtering (conformality controllable by deposition / sputter rate)
- Low temperature process (about 100 - 400°C)

CVD/CVD POLYSILICON

CVD Poly-silicon

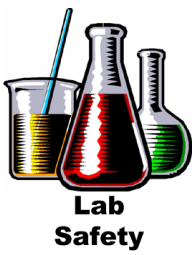
- Pyrolysis of silane: $SiH_4 \rightarrow Si + 2H_2$
  - LPCVD Process 1: 100% SiH_4, 0.2 - 1.0 torr
  - LPCVD Process 2: 30% SiH_4 in nitrogen, 0.2 - 1.0 torr
  - deposition rates: 10 - 20 nm/min
  - APCVD: 3% SiH_4 in nitrogen
- Caution: SiH_4 (silane) is pyrophoric, explodes when in contact with air

CVD/CVD POLYSILICON

CVD Poly-silicon

- Amorphous (< 600°C) or polycrystalline (> 600°C)
- Gate electrode in MOS devices (not anymore after 2007)
- Resistors, conductors in IC
- Structural material in MEMS
- Doping possible by
  - diffusion (atoms moving through crystals / solids)
  - implantation (impingement of high energy ions)

DETOUR: LAB SAFETY



FLAMMABILITY RANGE

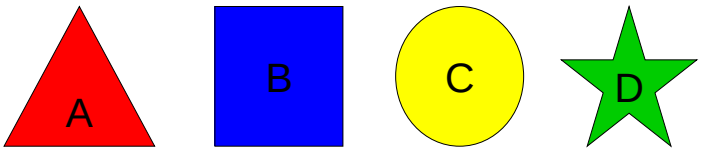
- Upper Explosive Limit (UEL)
- Lower Explosive Limit (LEL)
  - volume percent of substance in air that will sustain combustion
- Flammable Range: UEL - LEL, in percent
  - Example: Silane
    - UEL = 98.0% above this concentration, the mixture is too rich to burn.
    - LEL = 1.5% below this concentration, the mixture is too lean to burn.

FLAMMABILITY POINTS

- Flash Point: minimum temperature where a spark or flame will cause an instantaneous flash in the vapor space above a liquid
- Fire Point: minimum temperature of a liquid to support continuous combustion after ignition via a spark or flame
- Autoignition Point: minimum temperature at which a liquid spontaneously ignites without the introduction of a spark or flame
  - Example: Silane
    - autoignition point (AP) = <21 C
    - fire point = [usually about 20 C higher than the FP]
    - flash point (FP) = extremely flammable gas

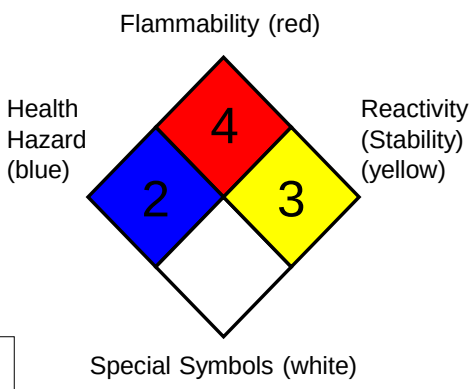
FIRE CLASSIFICATIONS

- Class A - common combustibles that leave coals or embers
- Class B - flammable liquids and gases
- Class C - fires in energized electrical equipment
- Class D - combustible metals: Al, Mg, Li, Na, K, Ti, Zr



NFPA 704M LABELING SYSTEM

- National Fire Protection Association (NFPA)
- Hazard Ratings; 0 to 4:
  - 0 none
  - 1 slight
  - 2 significant
  - 3 severe
  - 4 extreme
- Example: Silane



Some manufacturers, e.g. Baker, use the fourth (white) position to indicate immediate contact hazard

CVD/CVD SILICON DIOXIDE

	PECVD	LPCVD			
Deposition	SiH_4+O_2	SiH_4+O_2	TEOS	$SiCl_2H_2+N_2O$	Thermal
Temp °C	200	450	700	900	1000
Composition	$SiO_{1.9}(H)$	$SiO_2(H)$	SiO_2	$SiO_2(Cl)$	SiO_2
Step coverage	nonconf.	nonconf.	conf.	conf.	conformal
Thermal stability	loses H	densifies	stable	loses Cl	stable
Density (g/cm^3)	2.3	2.1	2.2	2.2	2.2
Refractive index	1.47	1.44	1.46	1.46	1.46
Stress (10^4 N/cm^2)	3C-3T	3T	1C	3C	3C
Dielectric strength (10^6 V/cm)	3-6	8	10	10	11
Etch rate (nm/min) 100:1 H_2O:HF	40	6	3	3	2.5
Dielectric constant	4.9	4.3	4.0	-	3.9

from S. M. Sze, VLSI Technology

CVD/CVD SILICON NITRIDE

- Amorphous dielectric, high resistivity
- Good barrier to diffusion

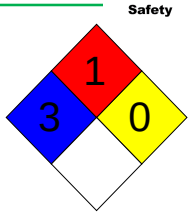
- $3SiH_4 + 4NH_3 \rightarrow Si_3N_4 + 12H_2$
- $3SiCl_2H_2 + 4NH_3 \rightarrow Si_3N_4 + 6HCl + 6H_2$

CVD/CVD SILICON NITRIDE

Deposition	LPCVD	Plasma
Temperature °C	700 - 800	250 - 350
Composition	$Si_3N_4(H)$	SiN_xH_y
Si/N ratio	0.75	0.8 - 1.2
Atom % H	4-8	20 - 25
Refractive index	2.01	1.8 - 2.5
Density (g/cm^3)	2.9 - 3.1	2.4 - 2.8
Dielectric constant	6 - 7	6 - 9
Resistivity (Ω-cm)	10^{16}	10^6 - 10^{15}
Dielectric strength (10^6V/cm)	10	5

from S. M. Sze, VLSI Technology

AMMONIUM HYDROXIDE (NH_4OH)



- created by dissolving NH_3 into H_2O
- NFPA704M code = 3-1-0; CAS # [1336-21-6]
- NH_3 is very soluble in H_2O
- forms a weak base (partially ionizes)
- neutralizes acids, but is generally unreactive with most metals
- standard reagent concentration is 30%, green bottle cap

- primary hazards:
  - concentrated NH_4OH will burn skin
  - NH_3 vapors are harmful
    - TLV = 50 ppm
    - moderately toxic, strong irritant to skin, eyes, and mucus membranes