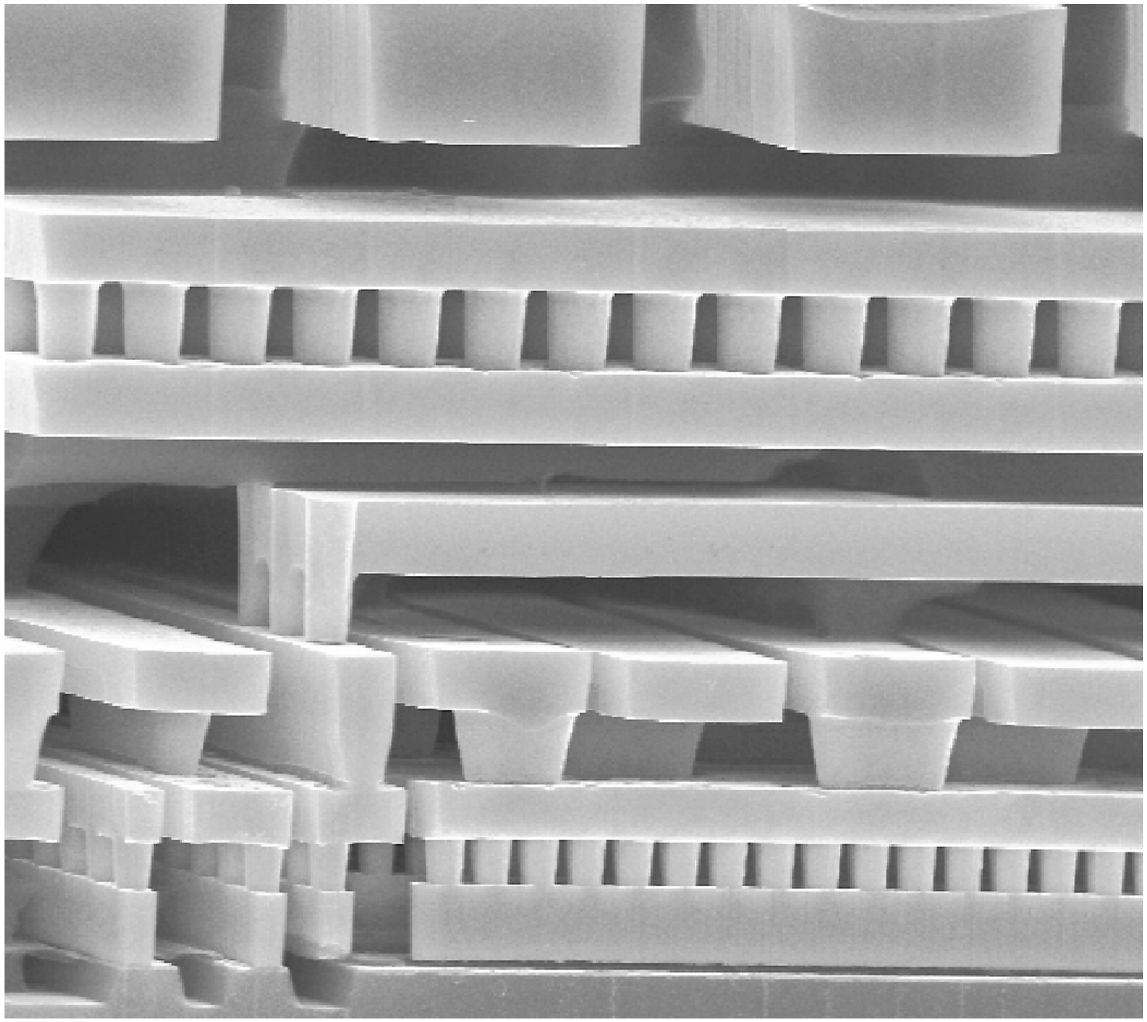
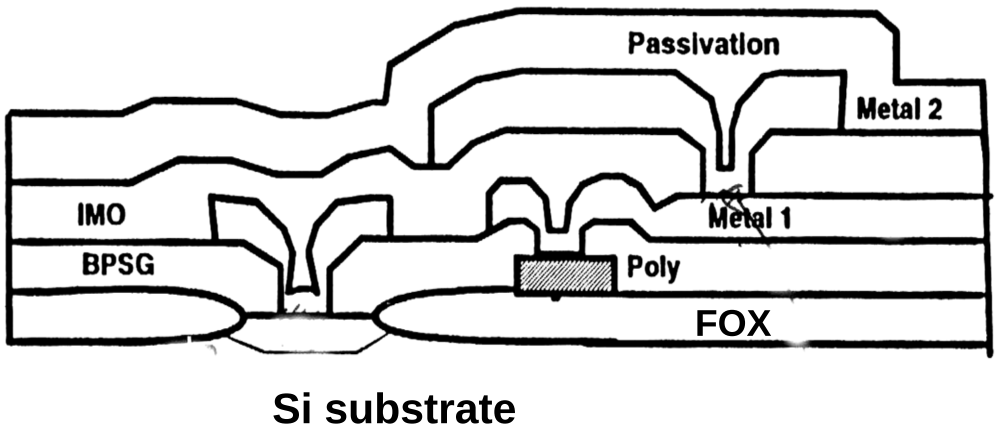
Section 8: Metallization

Jaeger Chapter 7

Multilevel Metallization



Multilevel Metallization Components



- **Interconnects**
- **Contacts - Metal to poly and doped Si**
- **Vias- Metal to metal contacts**
- **Intermetal Dielectric** **(InteMetal Oxide e.g. BPSG. Low-K dieletric)**
- **Passivation** **(e.g. PECVD Si Nitride)**

Interconnect RC Time Delay

Interconnect Resistance

$\mathbf{R_I}$ =R/L = ρ / ($W_{Al}T_{Al}$)

Interconnect-Substrate Capacitance

$\mathbf{C_V}$ ≡C/L = $W_{Al}\ \varepsilon_{ox}\ /\ T_{ox}$

Interconnect-Interconnect Capacitance

$\mathbf{C_L}$ ≡ C/L = $T_{Al}\ \varepsilon_{ox}\ /\ S_{Al}$

* Values per unit length L

Interconnect Requirements

- low ohmic resistance
  - interconnects material has low resistivity
- low contact resistance to semiconductor device
- reliable long-term operation

Resistivity of Metals

TABLE 7.1 Bulk Resistivity of Metals (μΩ-cm)

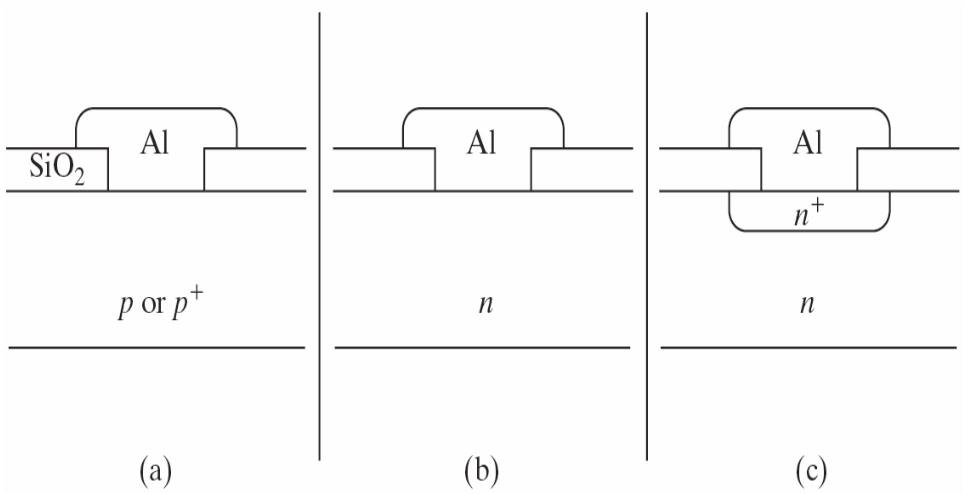
Ag: Silver	1.6
Al: Aluminum	2.65
Au: Gold	2.2
Co: Cobalt	6
Cu: Copper	1.7
Mo: Molybdenum	5
Ni: Nickel	7
Pd: Paladium	10
Pt: Platinum	10.6
Ti: Titanium	50
W: Tungsten	5

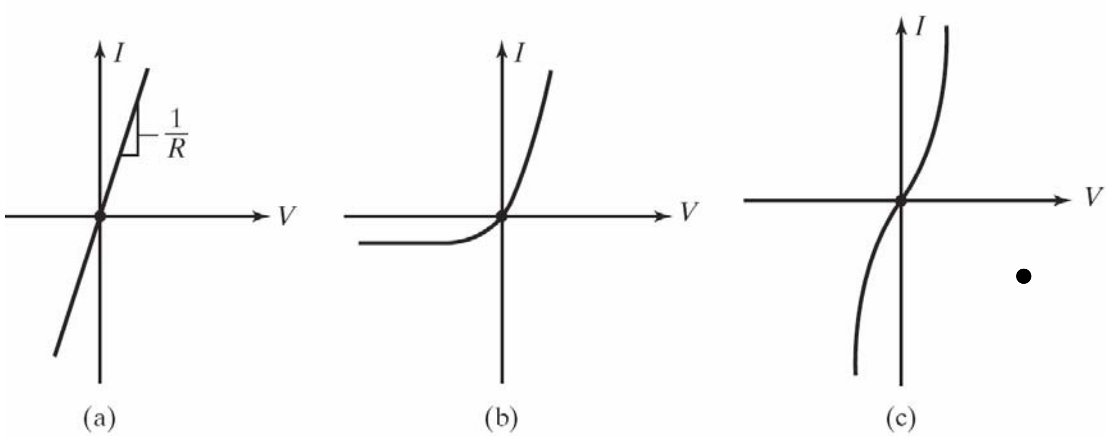
Source: WebElements [http://www.webelements.com]

Commonly Used Metals
- Aluminum
- Titanium
- Tungsten
- Copper

Less Frequently Utilized
- Nickel
- Platinum
- Paladium

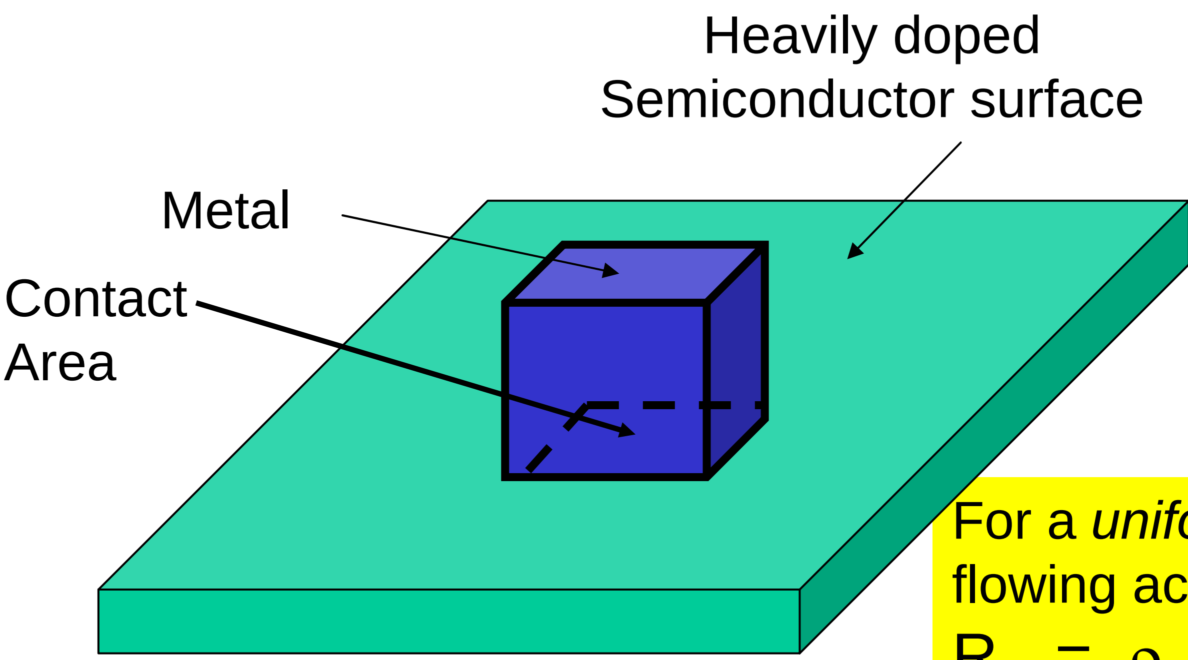
Ohmic Contact Formation





- Aluminum to p-type silicon forms an ohmic contact [Remember Al is p-type dopant]
- Aluminum to n-type silicon can form a rectifying contact (Schottky barrier diode)
- Aluminum to n+ silicon yields a tunneling contact

Contact Resistance Rc



For a *uniform* current density flowing across the contact area

$R_c = \rho_c$ / (contact area)

ρ_c of Metal-Si contacts ~ 1E-5 to 1E-7 Ω-cm^2

ρ_c of Metal-Metal contacts < 1E-8 Ω-cm^2

Contact Resistivity

Specific contact resistivity $\rho_c \equiv \left(\frac{\partial J}{\partial V}\right)^{-1}$ at V~0

$$\rho_c = \exp\left[\frac{2\sqrt{m^*\varepsilon_s}}{h}\left(\frac{\phi_B}{\sqrt{N}}\right)\right]$$

ϕ_B is the Schottky barrier height

N = surface doping concentration

ρ_c = specfic contact resistivity in ohm-cm^2

m = electron mass

h =Planck's constant

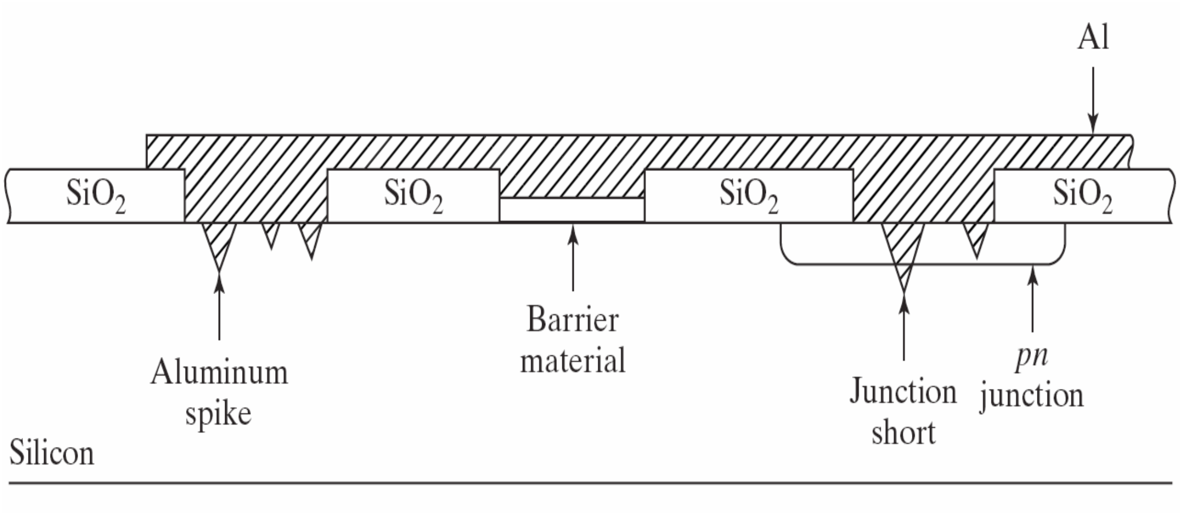
ε= Si dielectric constant

Approaches to lowering of contact resistance:

1) Use highly doped Si as contact semicodnuctor

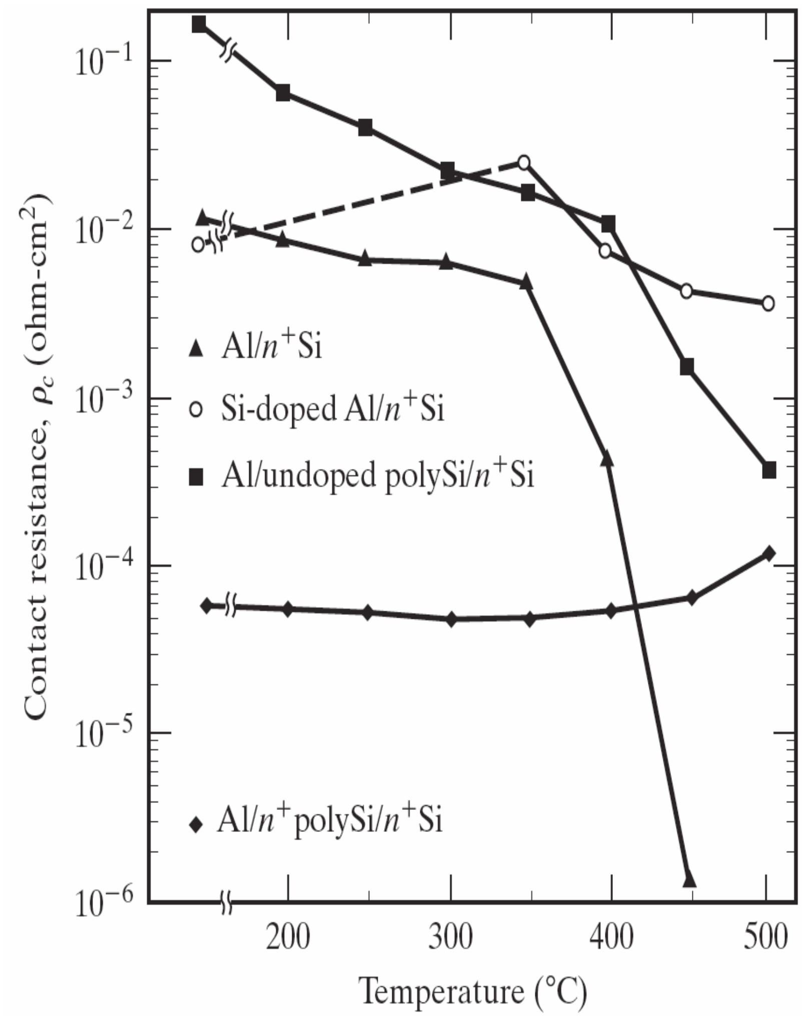
2) Choose metal with lower Schottky barrier height

Aluminum Spiking and Junction Penetration



- Silicon absorption into the aluminum results in aluminum spikes
- Spikes can short junctions or cause excess leakage
- Barrier metal deposited prior to metallization
- Sputter deposition of Al - 1% Si

Alloying of Contacts



Alloy to Obtain Very Low Contact Resistivity

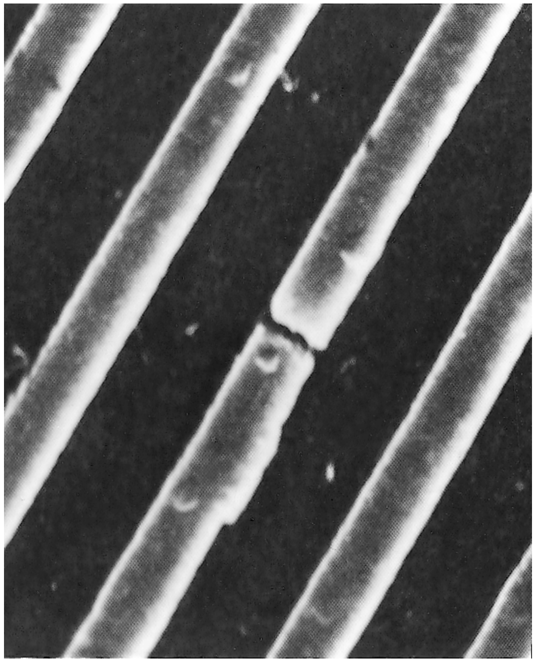
Specific Contact Resistivity

$$\rho_c = 1.2x10^{-6}\Omega - cm^2$$

Contact Resistance R_C

$$R_C = \frac{\rho_c}{A}$$ A = contact area

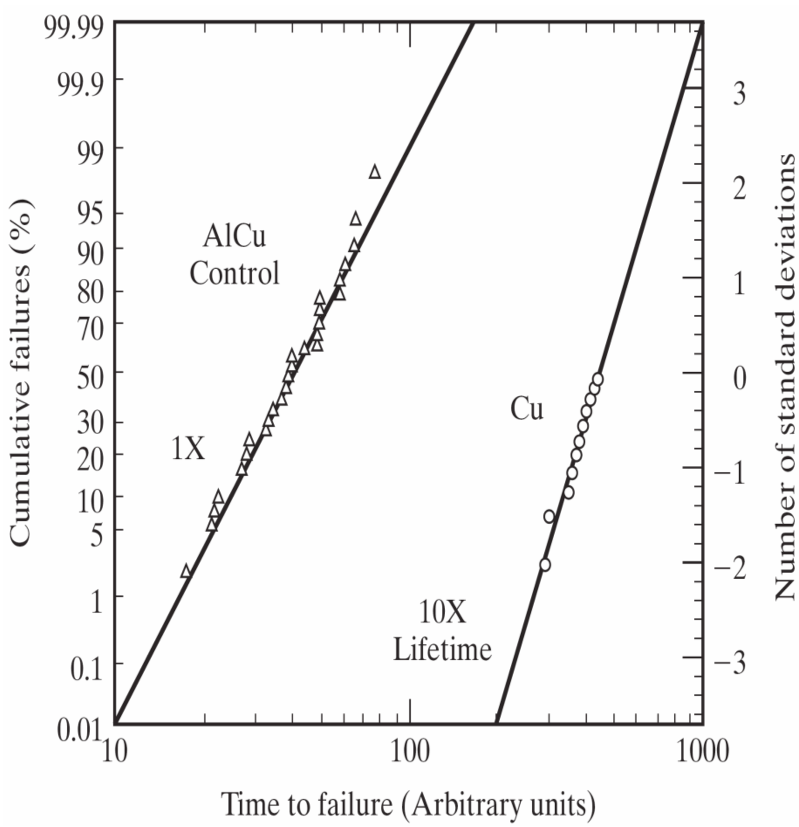
Electromigration



High current density causes voids to form in interconnections

“Electron wind” causes movement of metal atoms

Electromigration



- Copper added to aluminum to improve lifetime (Al, 4% Cu, 1% Si)

$$MTF \propto \frac{1}{J^2}\exp\left(\frac{E_A}{kT}\right)$$

J = current density

E_A = activation energy

MTF = mean time to failure

- Heavier metals (e. g. Cu) have lower activation energy

Metal Deposition Techniques

- Sputtering has been the technique of choice
  - high deposition rate
  - capability to deposit complex alloy compositions
  - capability to deposit refractory metals
  - uniform deposition on large wafers
  - capability to clean contact before depositing metal
- CVD processes have recently been developed

  (*e.g.* for W, TiN, Cu)
  - better step coverage
  - selective deposition is possible
  - plasma enhanced deposition is possible for lower deposition temperature

Metal CVD Processes

TiN

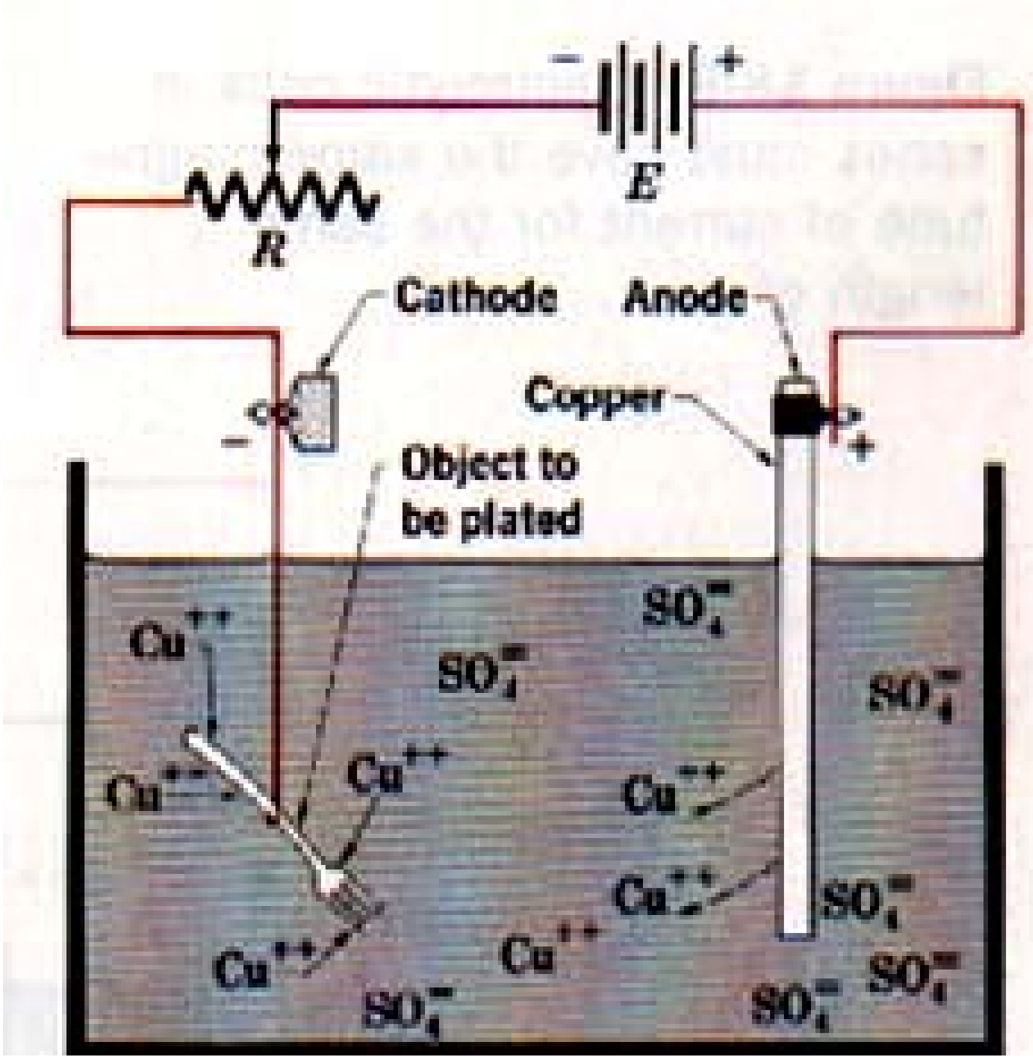
- used as barrier-metal layer
- deposition processes:

$$6TiCl_4 + 8NH_3 \rightarrow 6\boxed{TiN} + 24HCl + N_2$$

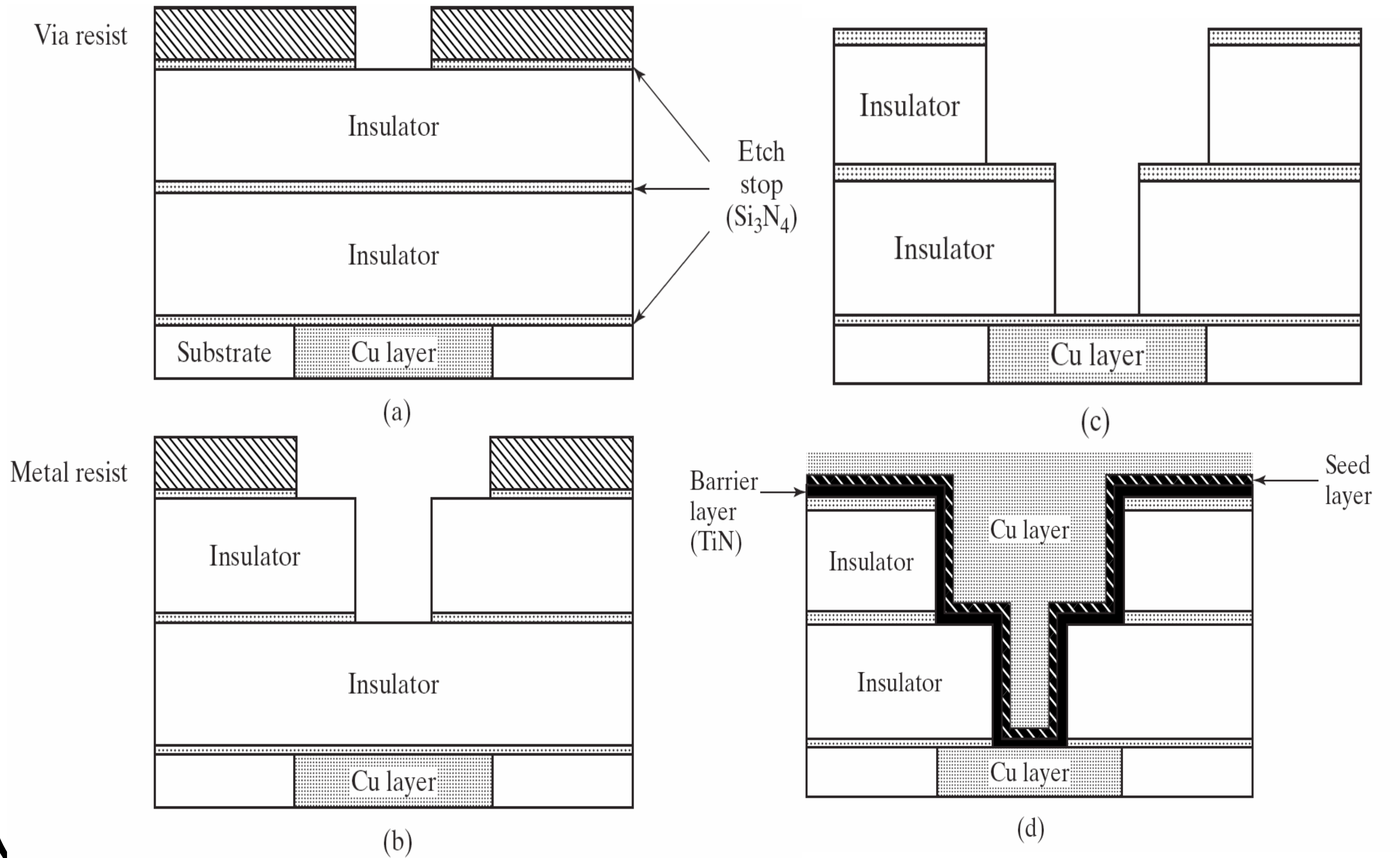
$$2TiCl_4 + 2NH_3 + H_2 \rightarrow 2\boxed{TiN} + 8HCl$$

$$2TiCl_4 + N_2 + 4H_2 \rightarrow 2\boxed{TiN} + 8HCl$$

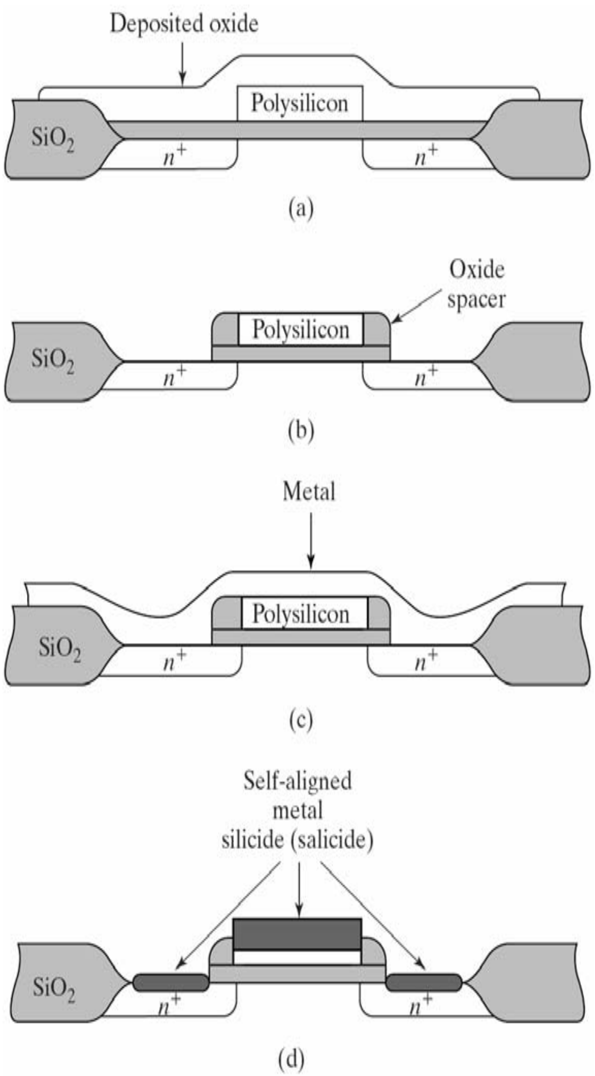
Electroplating



Dual Damascene Process

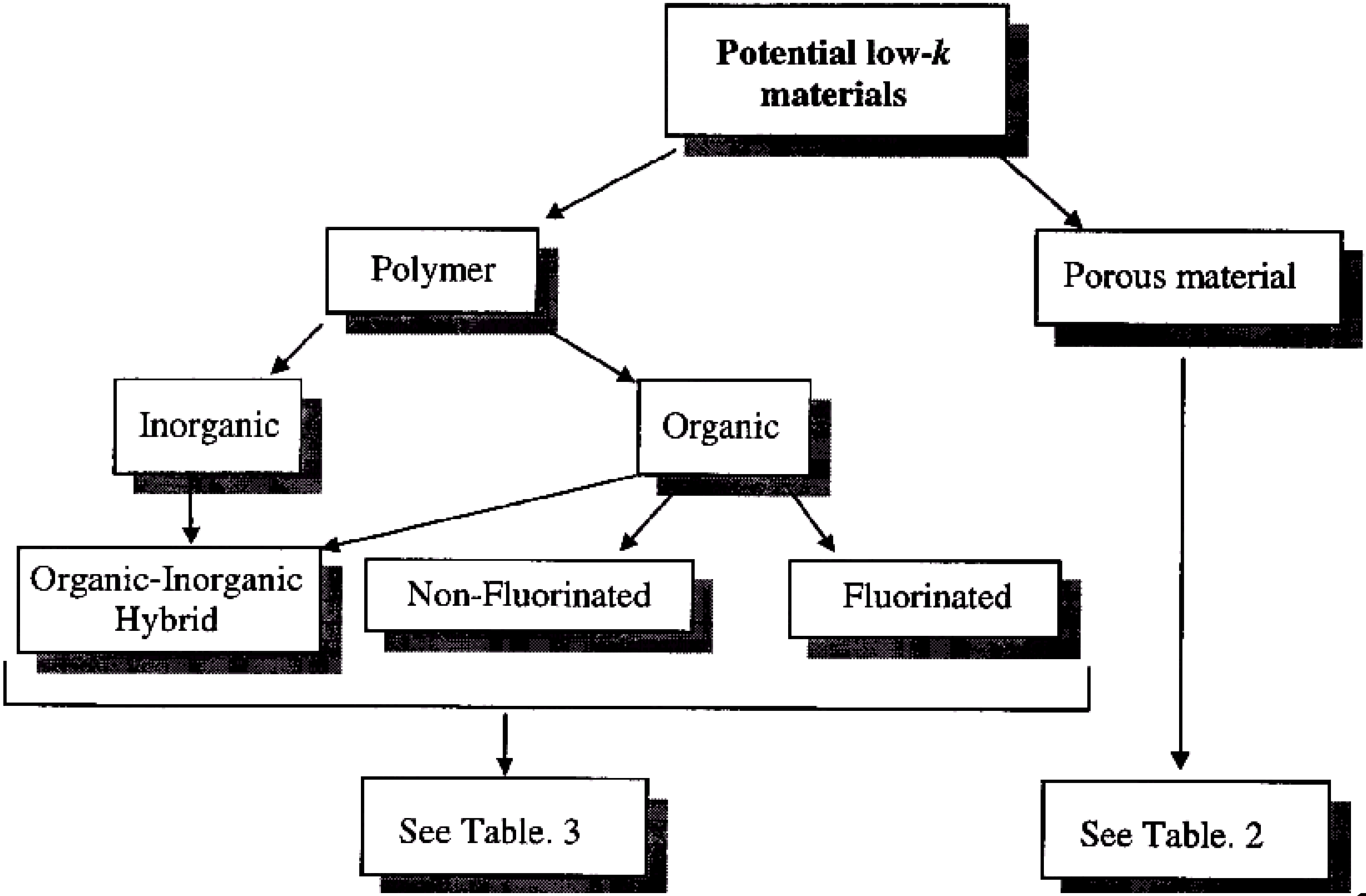


Salicides



- Self-Aligned Silicide on silicon and polysilicon
- Often termed "Salicide"

Low-K Dielectrics



Porous low-k dielectric examples

Materials	Dielectric constant
TEOS* – based glass [9]	4.2
Fluorinted high-density plasma oxide (F-HDP) [10]	3.5 – 3.6
Nanoporous silica [11]	1 – 2.7
Fluorinated Amorphous carbon films [12-13]	2.3 – 2.4
Hydrophobic porous SOG (HPS) [14]	2.5
Xerogels & aerogels [4,15-17]	1.3 – 3.0
Air [9]	1.0 –2.0