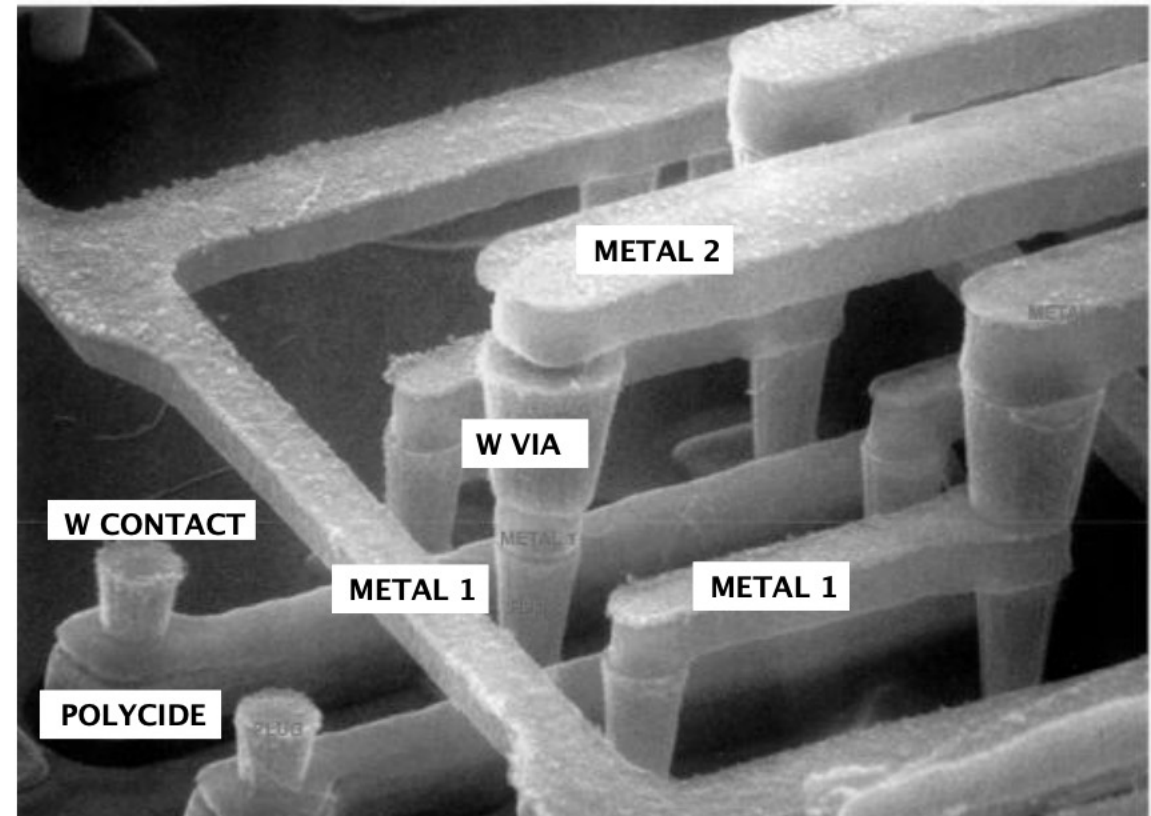
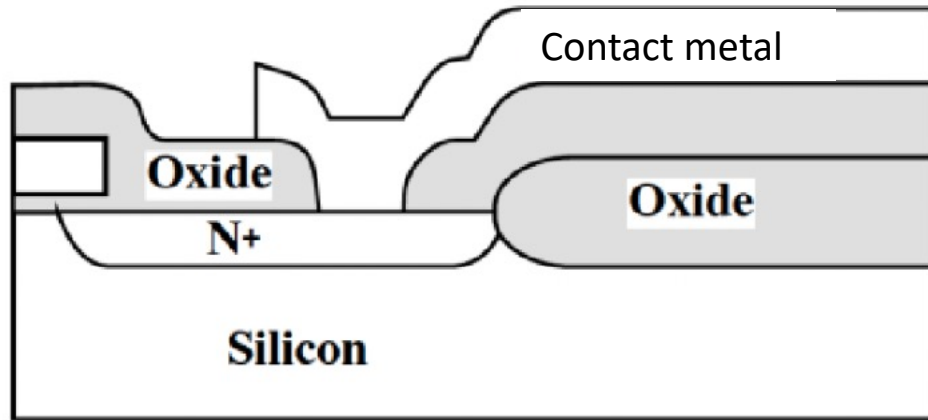


Metallization, Contacts and Interconnects



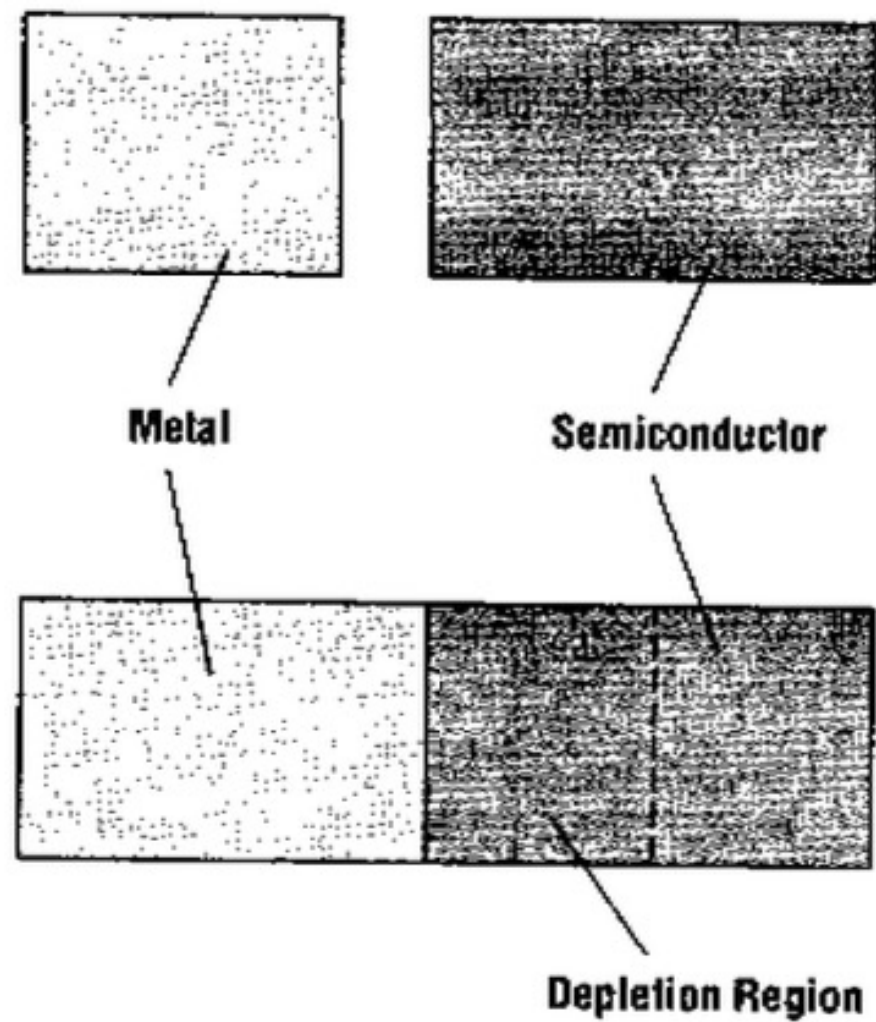
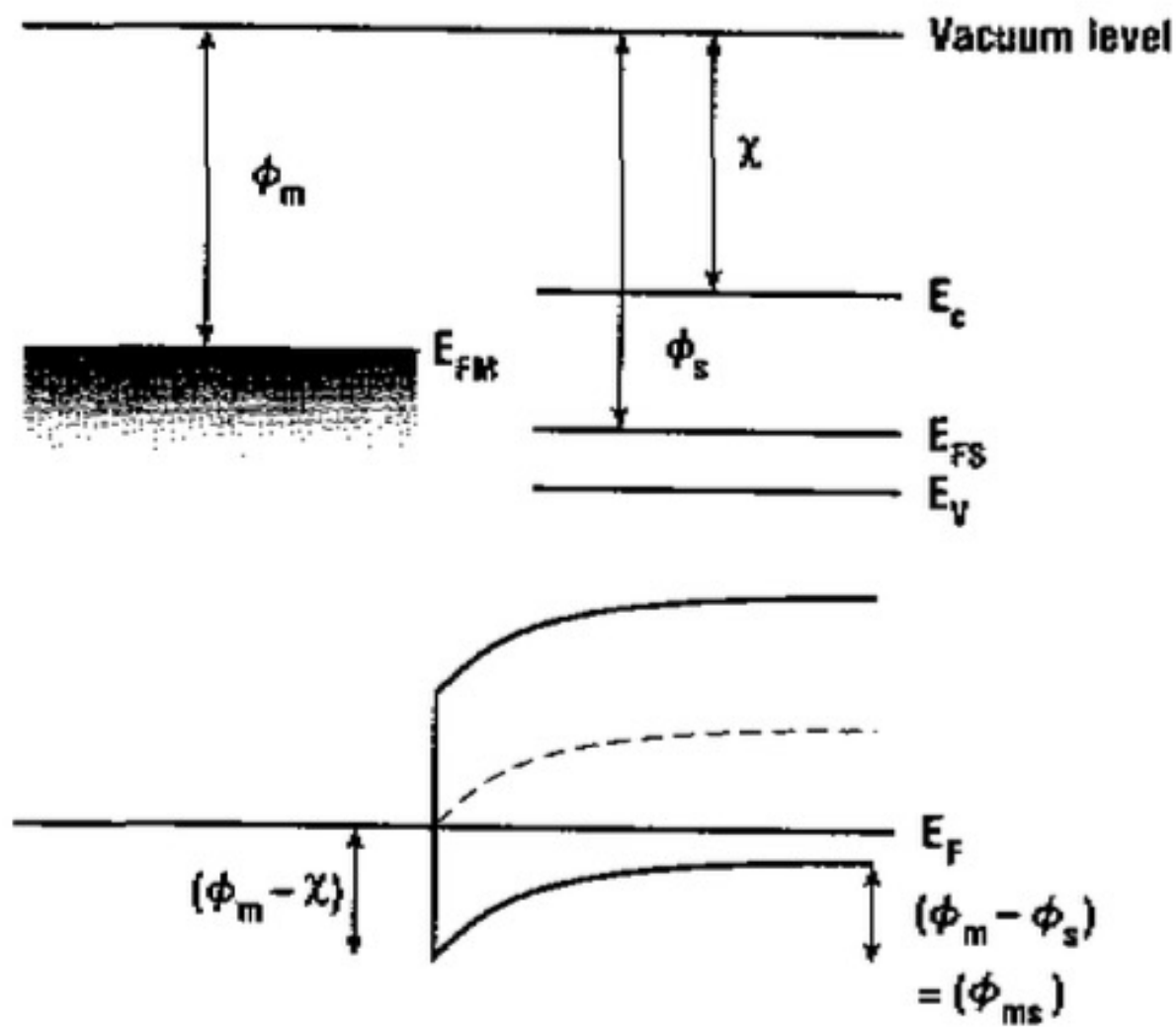
A proto-typical contact structure



Material	Thin film resistivity ($\mu\Omega\text{cm}$)	Melting point ($^{\circ}\text{C}$)
Al	2.7-3.0	660
W	8-15	3410
Cu	1.7-2.0	1084
Ti	40-70	1670
PtSi	28-35	1229
TiSi ₂	13-16	1540
WSi ₂	30-70	2165
CoSi ₂	15-20	1326
NiSi	14-20	992
TiN	50-150	~2950
Ti ₃₀ W ₇₀	75-200	~2200
polysilicon (heavily doped)	450-1000	1417

Al is the most commonly used metal ?

- Al has low electrical resistivity – low power loss
- It adheres well with SiO₂ and Si
- Al₂O₃ is more stable than SiO₂. Al also easily diffuses into Si forming contacts
- Al also passivates defect states! It reduces H₂O to pure Hydrogen.
- Most importantly, it forms Ohmic contacts with Si!

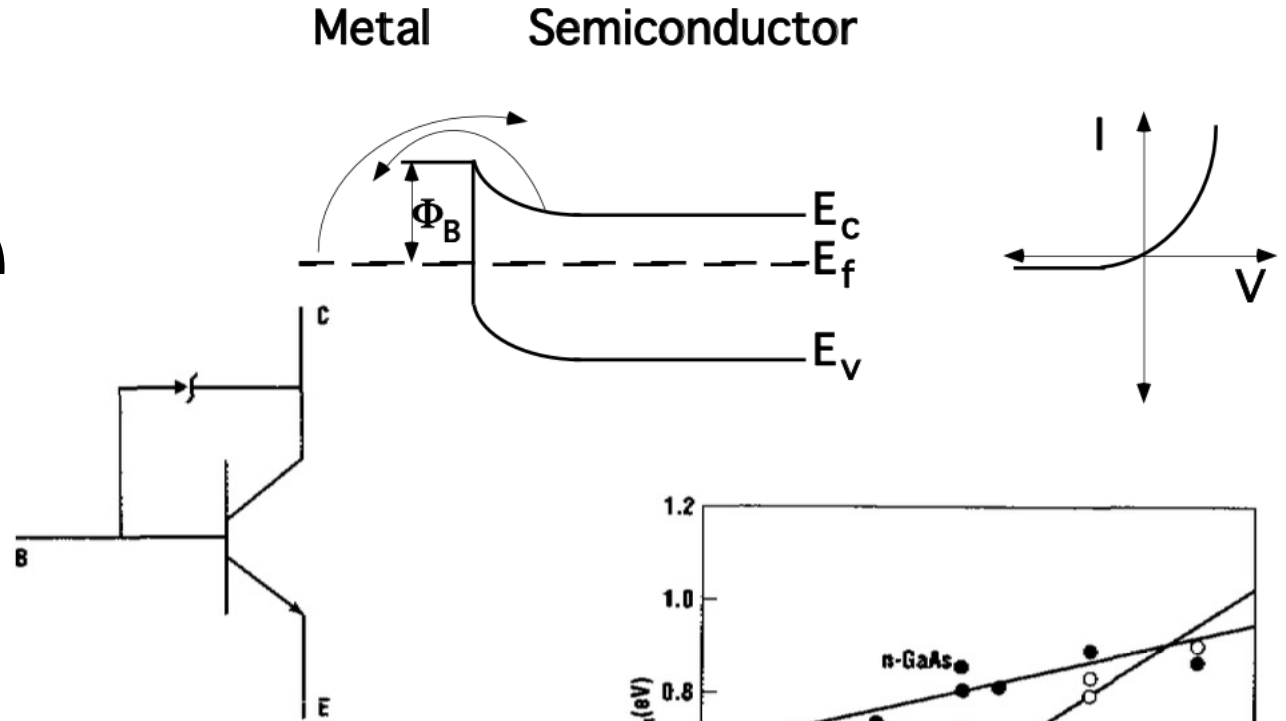


Current through a metal-semiconductor interface

- Current is

$$J_S = A^* T^2 e^{\frac{\phi_B}{KT}} \left(e^{\frac{qV}{KT}} - 1 \right)$$

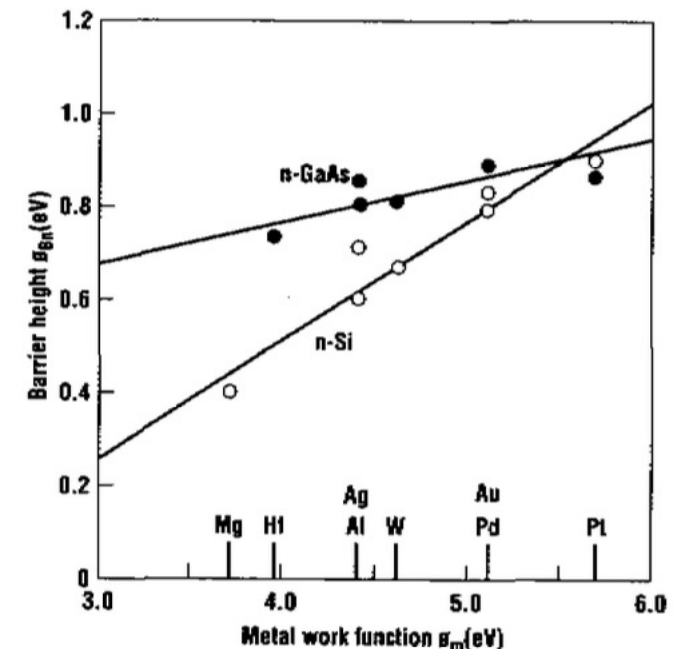
A^* is Richardson's constant



A Schottky barrier diode allows current in one direction and forbids in another.

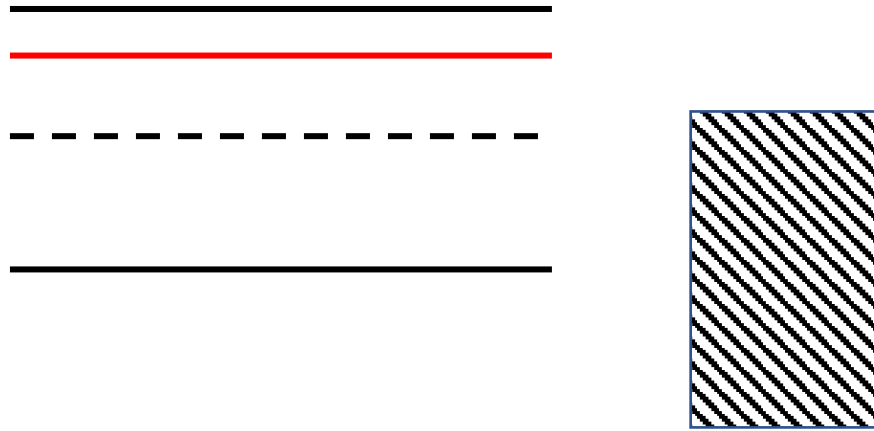
This has several applications:

1. Metal-semiconductor contacts.
2. Very-fast diode (doesn't have minority carriers storage problems)
3. Voltage clamping applications

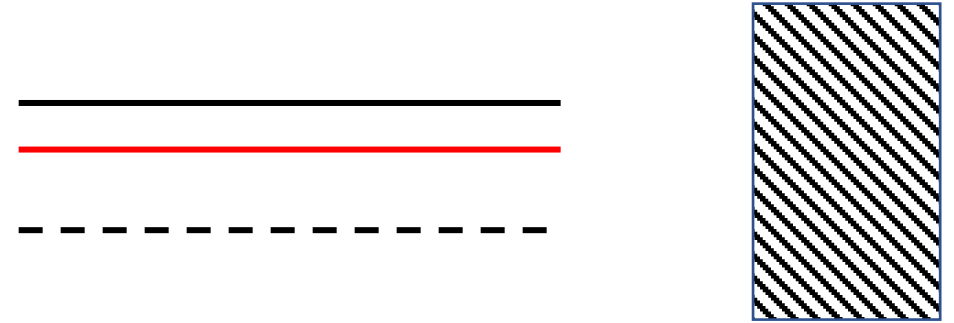
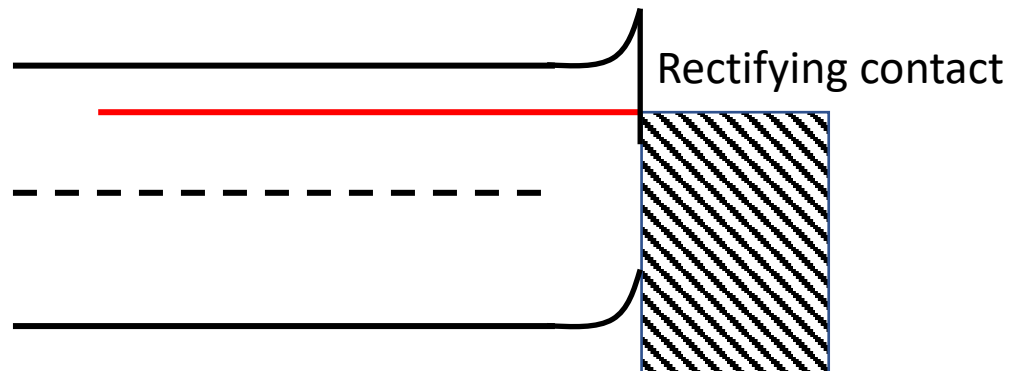


What is Ohmic then ?

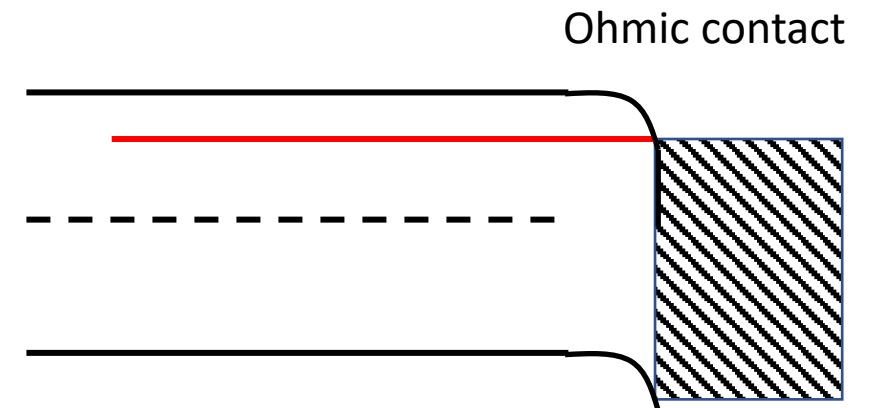
N-type semiconductor



Situation when the metal fermi level is lower than the semiconductor Fermi level.



Situation when the metal fermi level is higher than the semiconductor Fermi level.

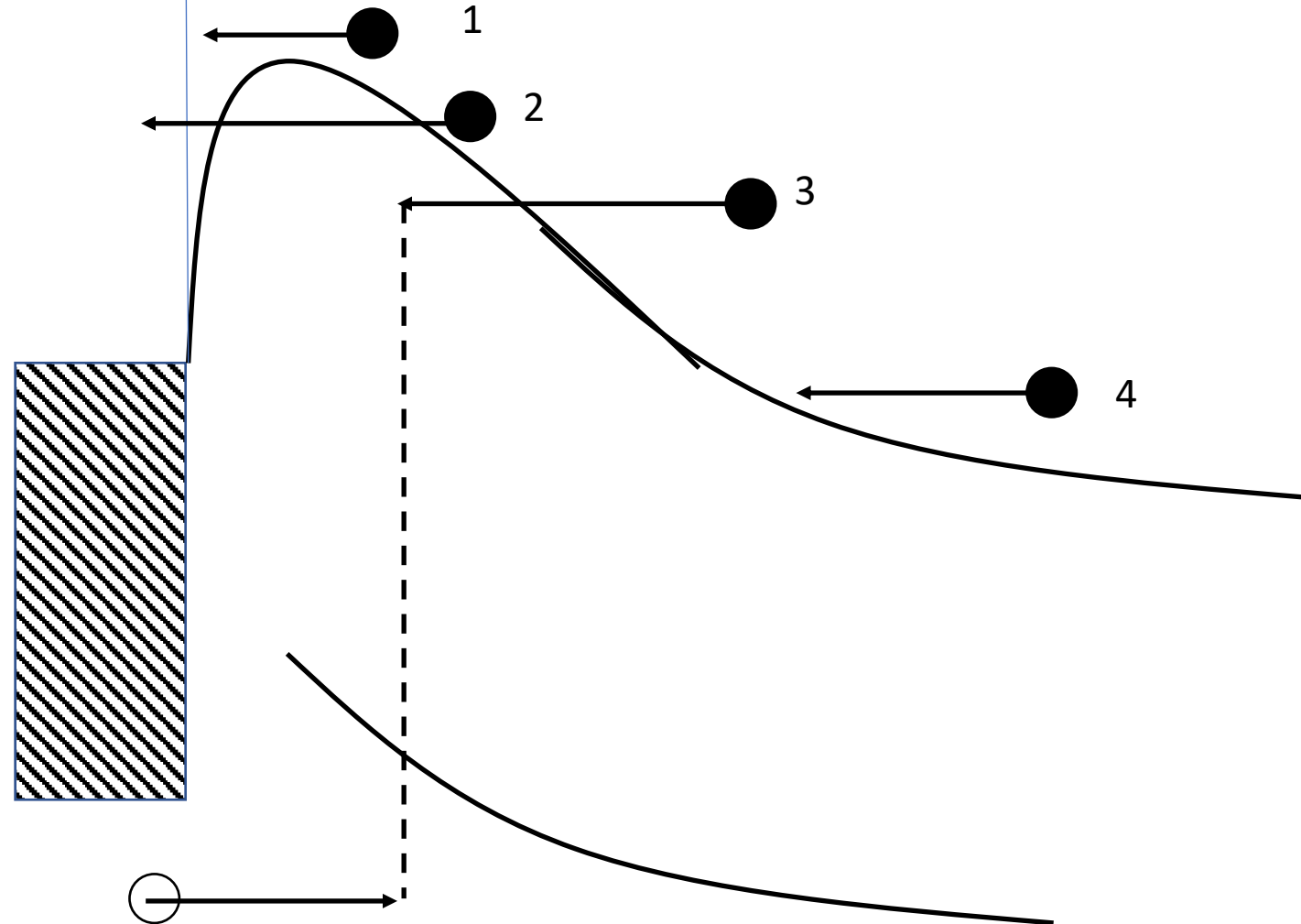


Transport across metal-semiconductor interfaces

Various processes involved in transport processes

1. Emission of electrons from semiconductor over the potential barrier
2. Quantum mechanical tunneling across the barrier
3. Recombination E-H pair in the depletion
4. Diffusion of injected carriers in the neutral region of semiconductors

For standard semiconductors with high mobility (long scattering length, mean life time), Thermal emission sufficiently describes the conduction process.



How to obtain Ohmic contacts?

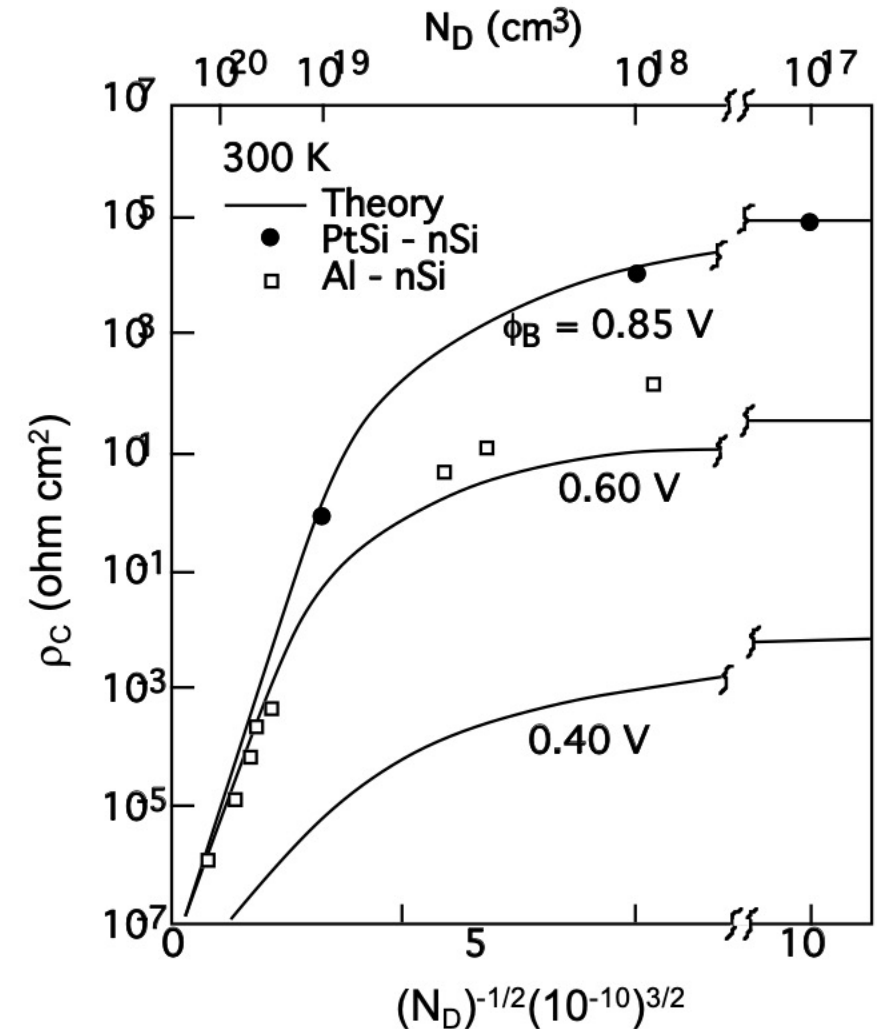
- Choose the right metal ? [Very few choices]
- For a chosen metallic contact:

$$J_s \propto e^{-2x_d \sqrt{\frac{2m^*(q\phi_B - qV)}{\hbar^2}}}$$

m^* is the effective mass

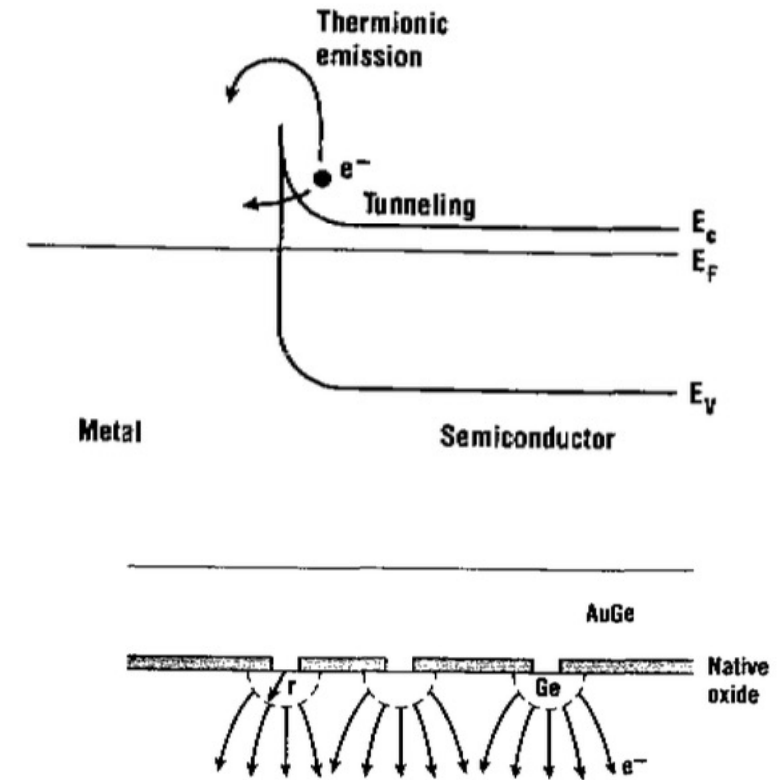
$x_d = \sqrt{\frac{2\epsilon_S \phi_B}{qN_D}}$ is the depletion width

Contact Resistivity $\rho_C = \left. \frac{\partial V}{\partial J} \right|_{V=0}$



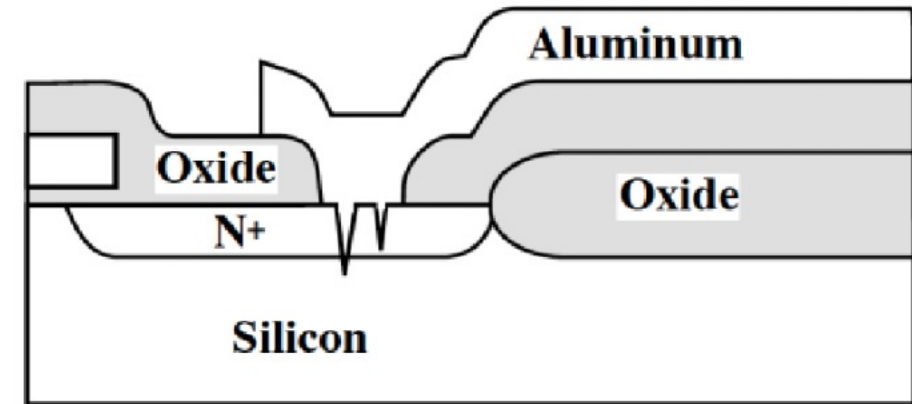
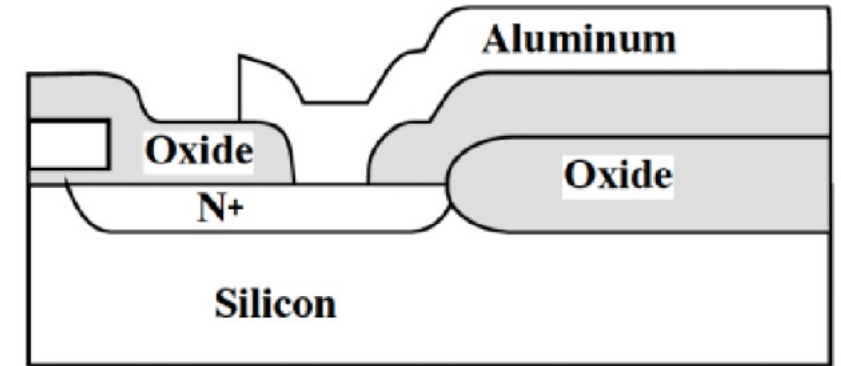
Alloyed contacts

- Unlike Si, GaAs and other group III-V materials required alloyed contacts
- Some example is a layer of Ni-Au-Ge
- When annealed at higher temperature
 - Au reacts with substrates to form Ga vacancies
 - Ge replaces Ga in those vacancies doping it n-type
 - The net contact resistance is now seriously reduced due to tunneling as described previously.



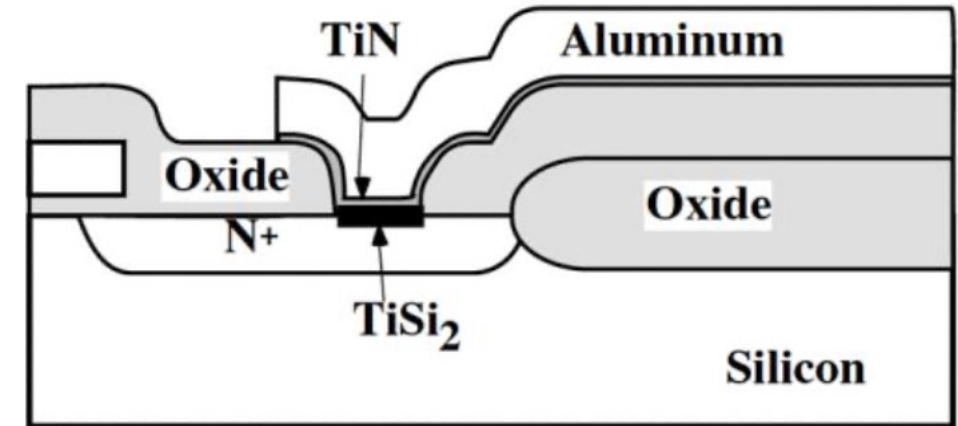
How are contacts made

- Say for a chosen metal like Al,
 - Post metal deposition, a thermal anneal at temperatures like 400C is done
 - This enables oxygen grabbing by Al and very good interface devoid of oxides
 - Al also diffuses into Si, forming good interface.
 - However, Si, diffuses faster into Al. Leaving holes.
 - This leads to Al spikes into Si. Causing junctions shorts! .
 - One solution: use Al-Si contacts – Excess Si in the Al prevents Si diffusion upwards!



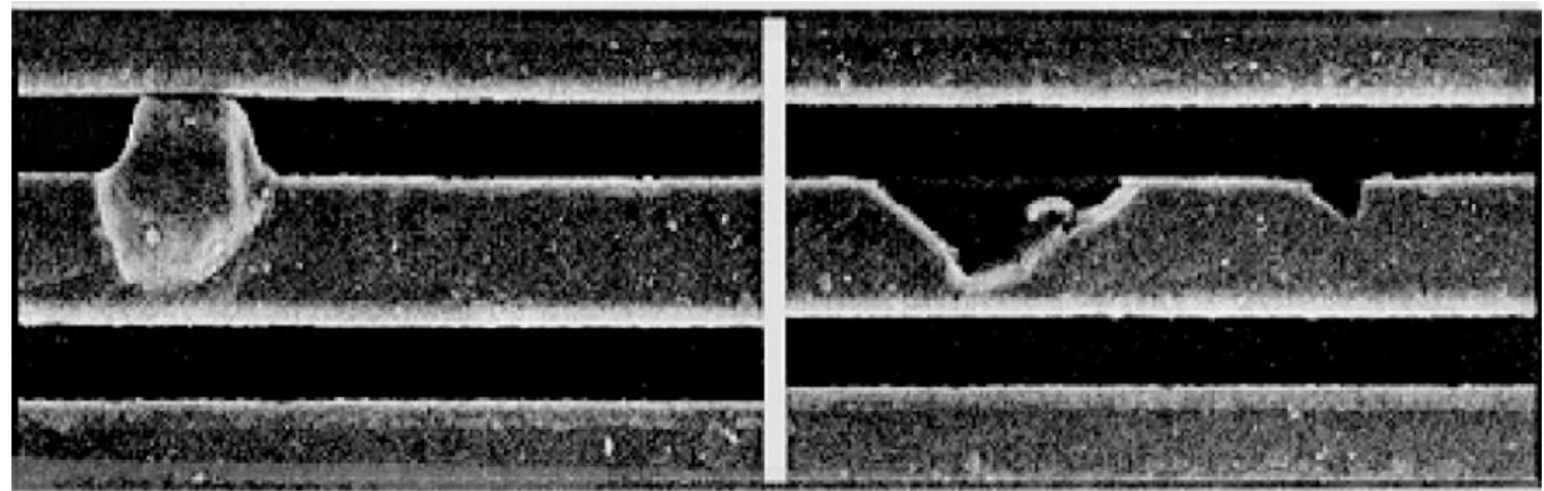
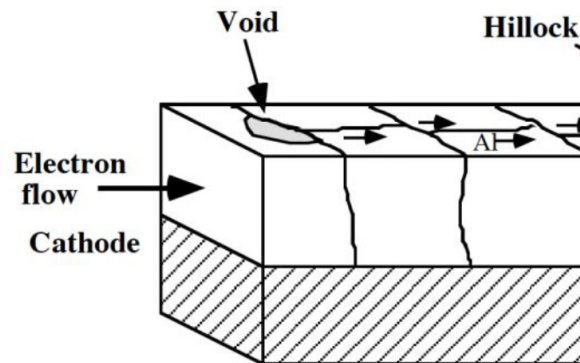
Passivated Contacts

- Si forms silicides with several metals
 - Pt-silicide can be formed at 350C.
 - Ti-W alloys are also good solutions above 400C.
 - Recently, TiN in an almost amorphous form is used. Grain boundaries in them do not permit diffusions easily.
 - A typical bi-layer with TiSi_2 for better adhesion and Ti-N for diffusion barriers are commonly employed.



Interconnections

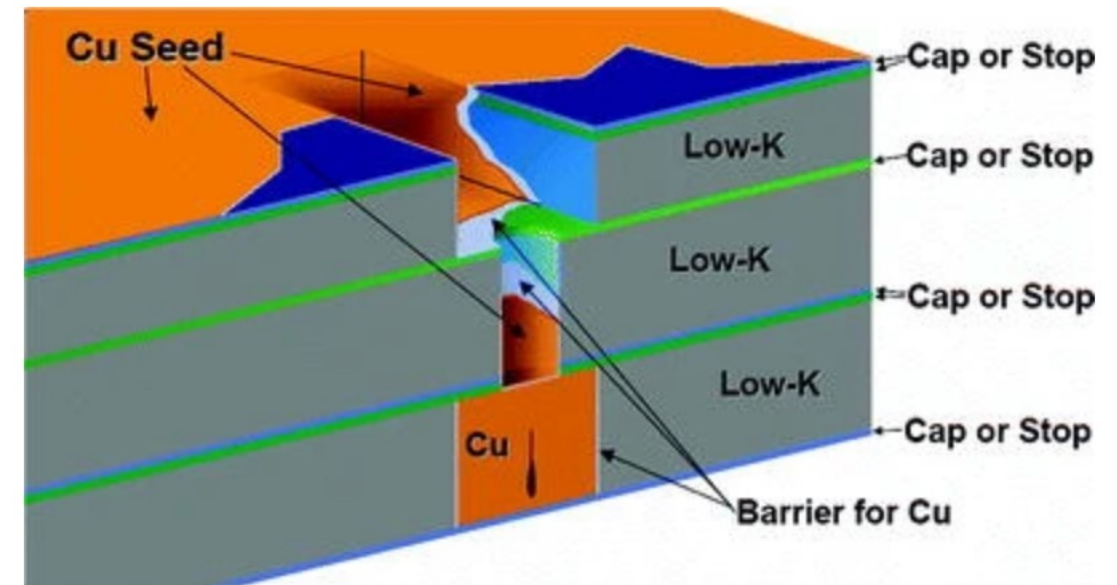
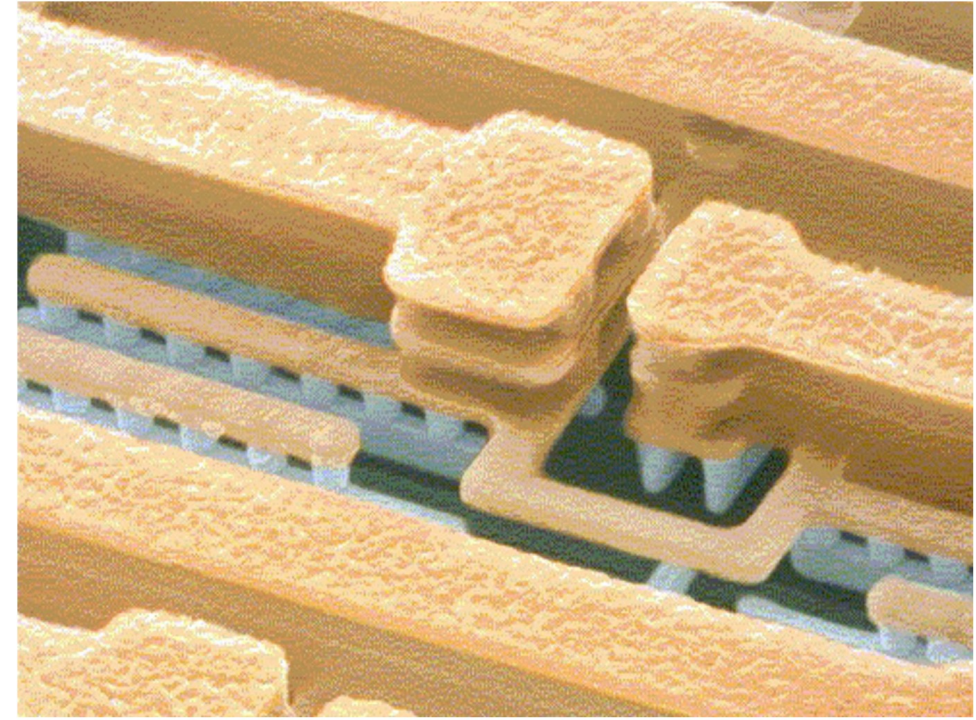
- Al is the most commonly used metal for interconnects due to low resistance
- Common problems are due to low stability at higher temperatures
- It is often coupled with poly-Si for low level contacts
- Two major problems with Al:
 - Al is so soft, it forms hillocks.
 - And it electromigrates



essive
in Al

Cu Interconnects

- Cu forms deep level traps
- Frequencies greater than 3 GHz requires better conductivity (lower R)
- A Damascene routine is employed.
 - Electroplating
 - Chemical polishing.



Di-electrics in interconnects

- The interconnections and other metals require electrical isolation
- It is provided by dielectrics
- The qualities required are
 - Electrical breakdown field $> 5 \text{ MV/cm}$
 - Low –leakage – bulk resistivity $> 10^{15} \text{ Ohm cm}$
 - Low dielectric constant – less capacitive coupling
 - Good adhesion to Si, thermal stability
 - Low intrinsic stress
 - Does not collect moisture

Material class	Material	Dielectric constant	Deposition technique
Inorganic	SiO ₂ (including PSG and BPSG)	3.9-5.0	CVD Thermal oxidation Bias-sputtering High density plasma
	Spin-on-glass (SiO ₂) (including PSG and BPSG)	3.9-5.0	SOD
	Modified SiO ₂ (e.g. fluorinated SiO ₂ or hydrogen silsesquioxane - HSQ)	2.8-3.8	CVD/SOD
	BN (Si)	>2.9	CVD
	Si ₃ N ₄ (only used in multilayer structure)	5.8-6.1	CVD
Organic	Polyimides	2.9-3.9	SOD/CVD
	Fluorinated polyimides	2.3-2.8	SOD/CVD
	Fluoro-polymers	1.8-2.2	SOD/CVD
	F-doped amorphous C	2.0-2.5	CVD
Inorganic/Organic Hybrids	Si-O-C hybrid polymers based on organo-silsesquioxanes (e.g. MSQ)	2.0-3.8	SOD
Aerogels (Microporous)	Porous SiO ₂ (with tiny free space regions)	1.2-1.8	SOD
Air bridge		1.0-1.2	

