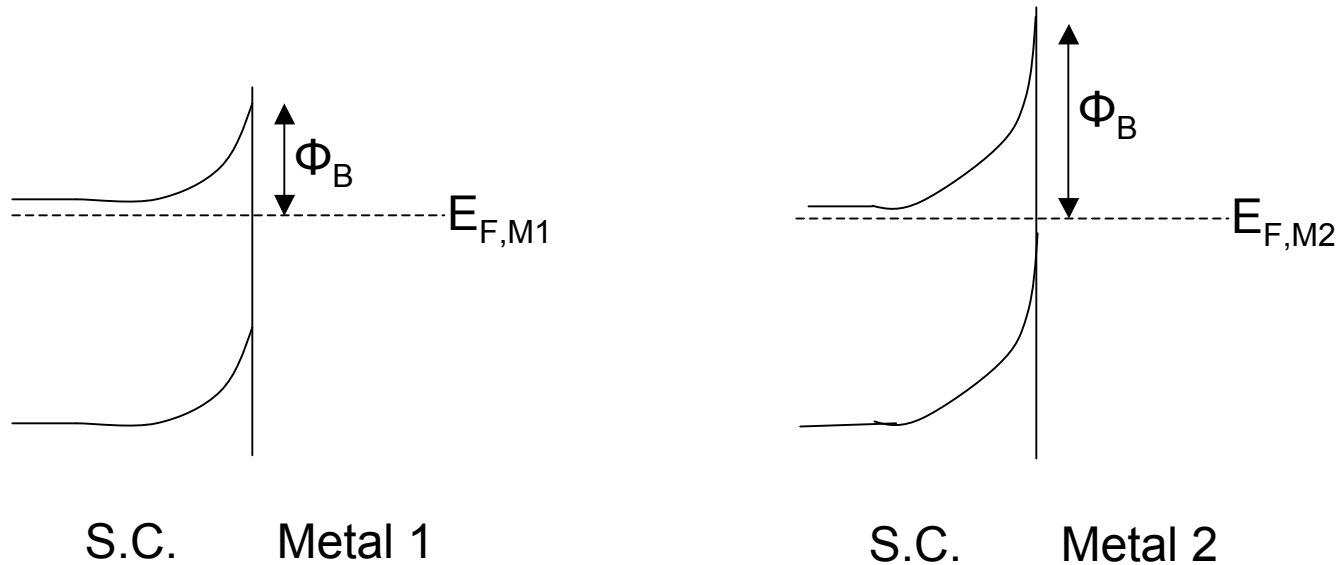


Lecture Note

Class #8, 9

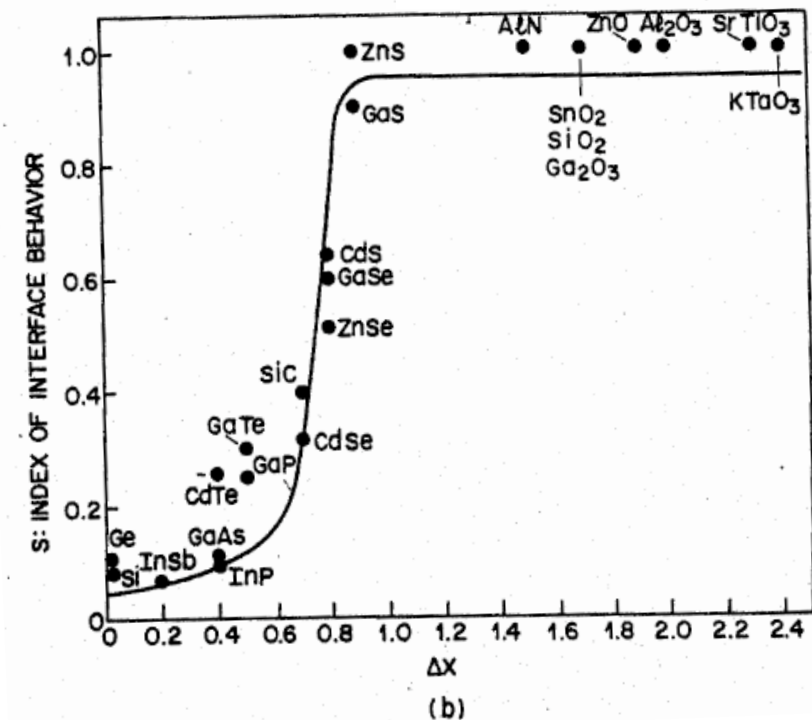
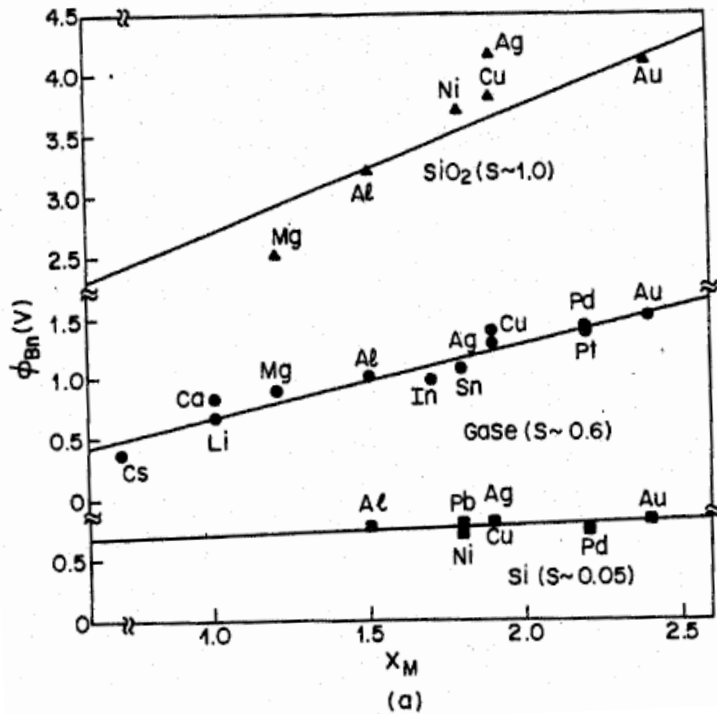
Jang Wook Choi

Fermi Energy Pinning



Expect that Φ_B depends on $E_{F, M}$

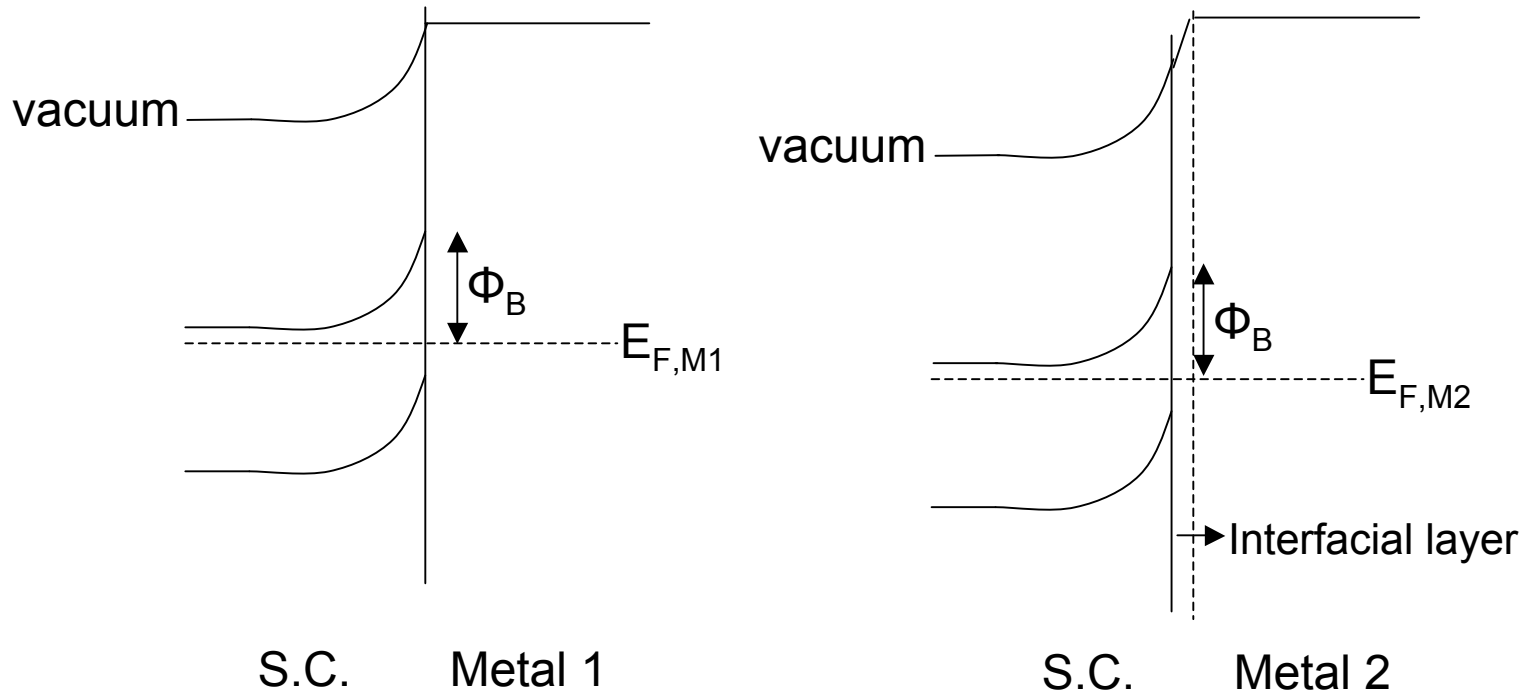
But, This is not the case for some semiconductors.



Observed a Barrier height that is independent of the contacting metal.

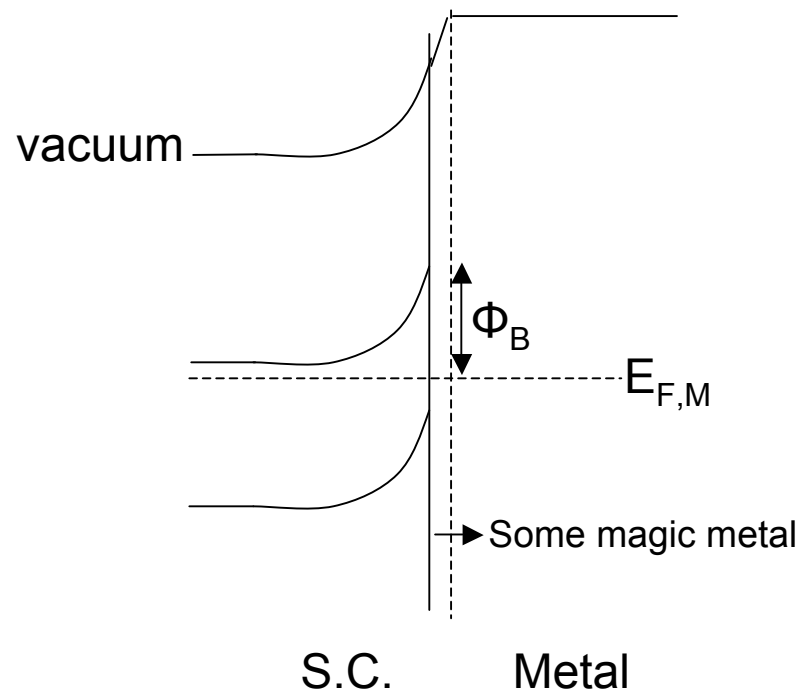
For example, $\Phi_B = 0.8 \sim 0.9$ V for Si.

Why does this happen?



$$\Phi_{B,1} = \Phi_{B,2} \text{ but, } E_{F, M1} \neq E_{F, M2}$$

→ Band Edge Unpinning



Exercise)

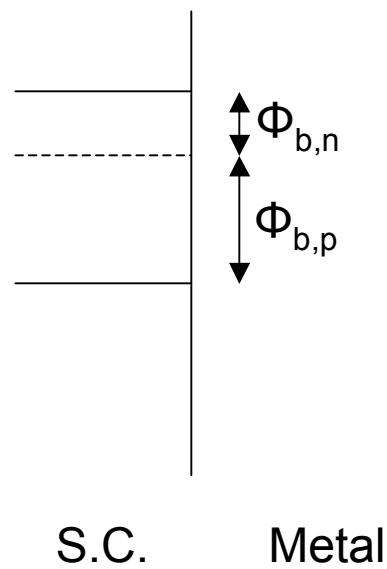
Very clean Si / Magic Metal / Metal

You see the Fermi energy pinning because Si / magic Metal interface always determines Si band bending.

→ Si never sees outer metal layer.

For real Si/Metal contact, Si dangling bonds, surface states, metal silicides and so on can be the interfacial layer.

Φ_B values for S.C/Metal



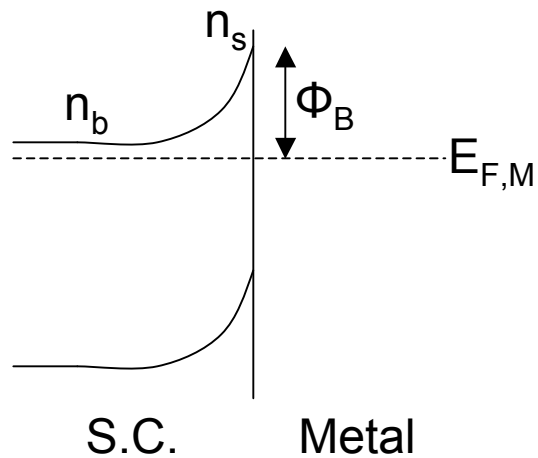
	$\Phi_{b,n}$	$\Phi_{b,p}$
Si	0.7~0.8	0.3~0.4
GaAs	0.9	0.5
InP	0.5	0.85

(Unit: V)

$\Phi_{b,n}$: Barrier for e^-

$\Phi_{b,p}$: Barrier for h^+

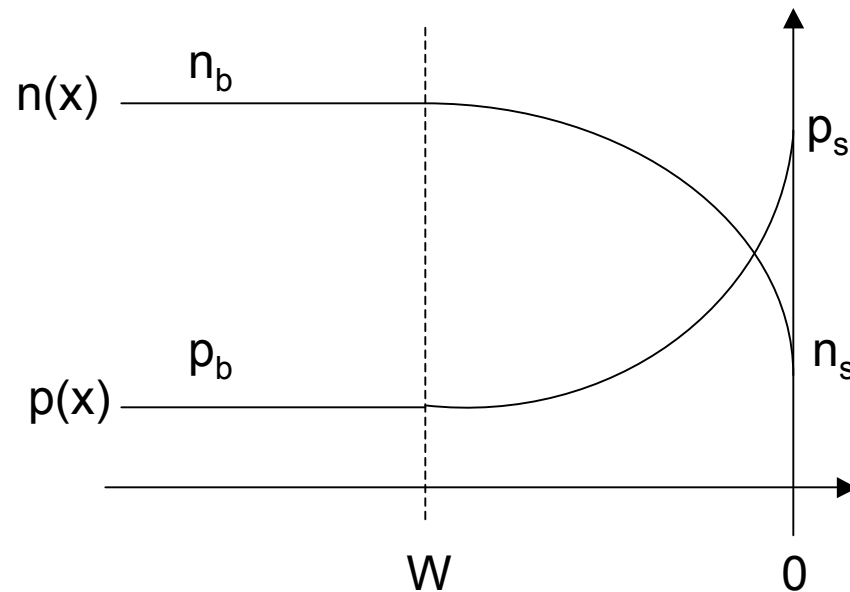
Equilibrium – Before applying bias



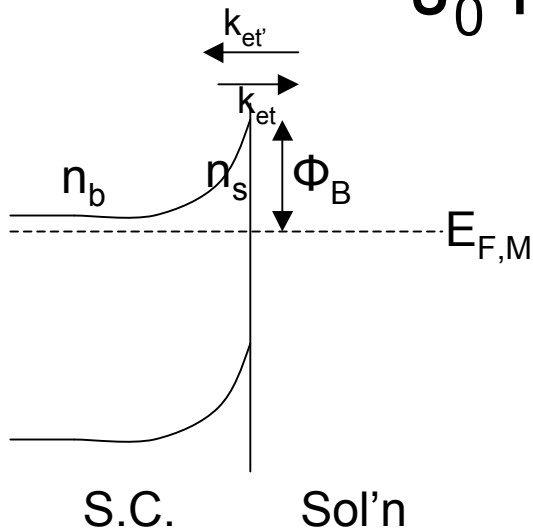
$$n(x) = n_b \exp[-qV(x) / kT]$$

@Surface, $n_s = n_b \exp[-qV_{bi} / kT]$

$np = n_i^2$ still holds.



J_0 for Solution Contact



Same as for metal, but now $[A]$ matters,

$$\text{flux} = n_s[A]k_{et} - k_{et'}[A^-]$$

$$\text{@Eq. } ns_0[A]k_{et} = k_{et'}[A^-]$$

$$\text{flux} = k_{et}[A](n_s - n_{s0})$$

k_{et} depends on

-reorganization energy of A/A^-

-probability that e^- will cross interface when at the right energy

$$\text{Current} = q \cdot \text{flux} = qk_{et}[A]n_{s0}\left(\frac{n_s}{n_{s0}} - 1\right) = J_{0,\text{soln}}[\exp(-qV_{bi}/kt) - 1]$$

$$J_0(\text{soln}) \ll J_0(\text{metal}) \text{ since } k_{et} \ll k_n$$

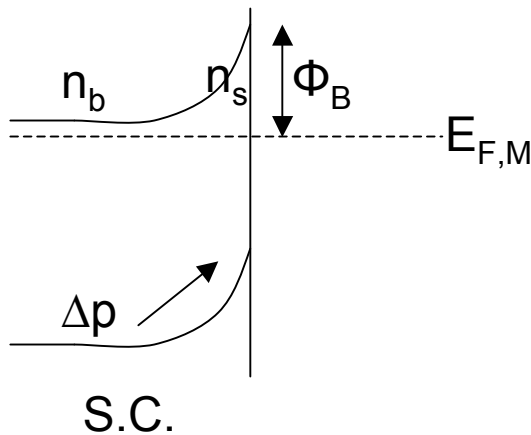
Shine Light

$$h\nu \rightarrow e^- + h^+$$

Low-level injection condition: $h\nu \rightarrow 10^{10} \sim 10^{11}$ carriers cm^{-3}

$$\Delta n \ll n, \Delta p \gg p$$

Light doesn't affect majority carrier. So you have same electron current, however, now you have much more holes.



Holes under electric field are attracted to the interface and transferred.

Good assumption: all Δp are transferred under the field.

This assumption can be true whatever V_{appl} is applied.

→ can add a constant value to the observed current

→ Superposition ($J = -J_0[\exp(-qV_{\text{bi}}/kT) - 1] + J_{\text{ph}}$)

Quantum Yield

$$\text{External Quantum Yield} = \frac{J_{ph}}{P_0}$$

$$\text{Internal Quantum Yield} = \frac{J_{ph}}{(1-R)\alpha_{abs}P_0} \quad \text{R:reflectivity, } \alpha: \text{absorption factor}$$

I.Q.Y. doesn't account for the loss by absorption efficiency.

For Solar cell devices, E.Q.Y. is what is going to determine the market ability. So this is what we should be looking at.

When Superposition Fails

↔ When not all Δp cross the interface

1. at high $-V$, which unbends the bands.
2. Low band bending cases: low Φ_b
3. Low k_{et} in the interface: S.C./M never shows the failure of superposition.

S.C/Soln sometimes can.

Open Circuit Voltage

$$0 = -J_0[\exp(-qV_{oc}/kT) - 1] + J_{ph} \rightarrow J_{ph} = J_0[\exp(-qV_{oc}/kT) - 1]$$

For $V_{oc} \gg 3kT/q$, 1 can be ignored.

$$|V_{oc}| = \frac{AkT}{q} \ln\left(\frac{J_{ph}}{J_0}\right) \rightarrow J_0 \text{ must be minimized for better solar cell devices}$$