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Fermi Band diagram In MOS Devices

Always wondered how an Nmos device functions on electron level?

This blog will answer all your questions. Fermi energy is a quantum mechanic concept which refers to the energy difference between the highest and lowest energy state occupied by a single particle in a quantum system of non-interacting fermions at absolute zero temperature. Fermi level is the concept used to describe the top of collection of electron energy levels at absolute zero temperature. Fermi level is “surface of sea” at absolute zero where no electrons will have enough energy to rise above that surface. Fermi energy is the value of the Fermi level at absolute zero temperature (−273.15 °C). It can also be referred as the maximum kinetic energy an electron can attain at 0K

.So the Fermi Function gives the probability that a given available electron energy state will be occupied at a given temperature.

$$f(E) = \frac{1}{1 + \exp\left(\frac{E - E_F}{k_B T}\right)}$$

Here Ef=Fermi energy

kb=Boltzmann constant

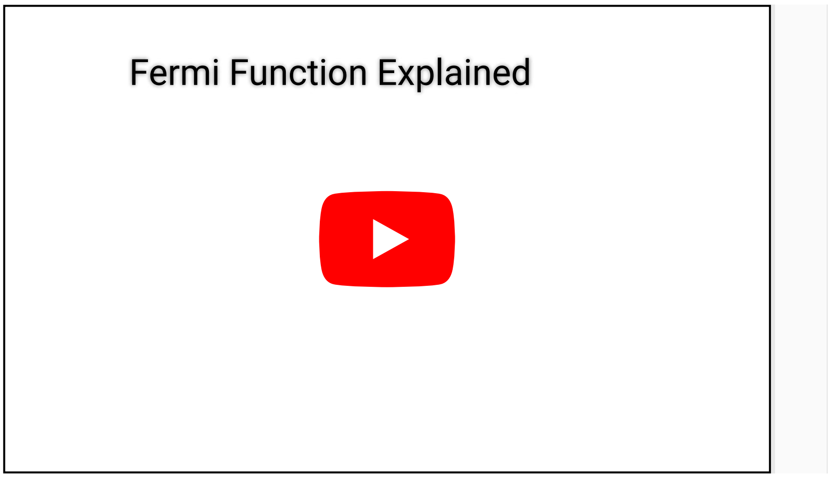
T=Temperature

KbT=Thermal Energy

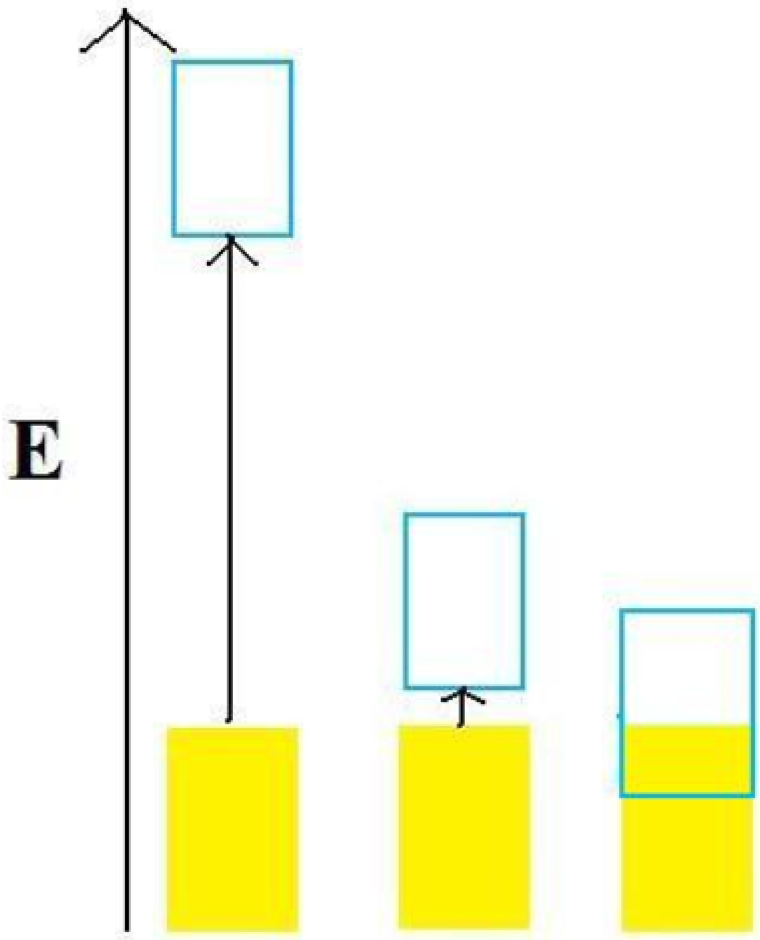
level is around 7ev (electron volts) for copper. By putting these nominal values, we observe that fermi function's value is 1 upto fermi level at ordinary temperatures and approaches to zero above fermi level Ef.

How are the electrons distributed in the energy levels at a given temperature?

As the electrons follow pauli's exclusion principle and are indistinguishable particles. The Pauli's exclusion principle postulates that only one fermion can occupy a single quantum state, so as the fermions are added to an energy band they fill the energy band just like water fills the bucket. In other words states with the lowest energy are filled first followed by the next higher ones.

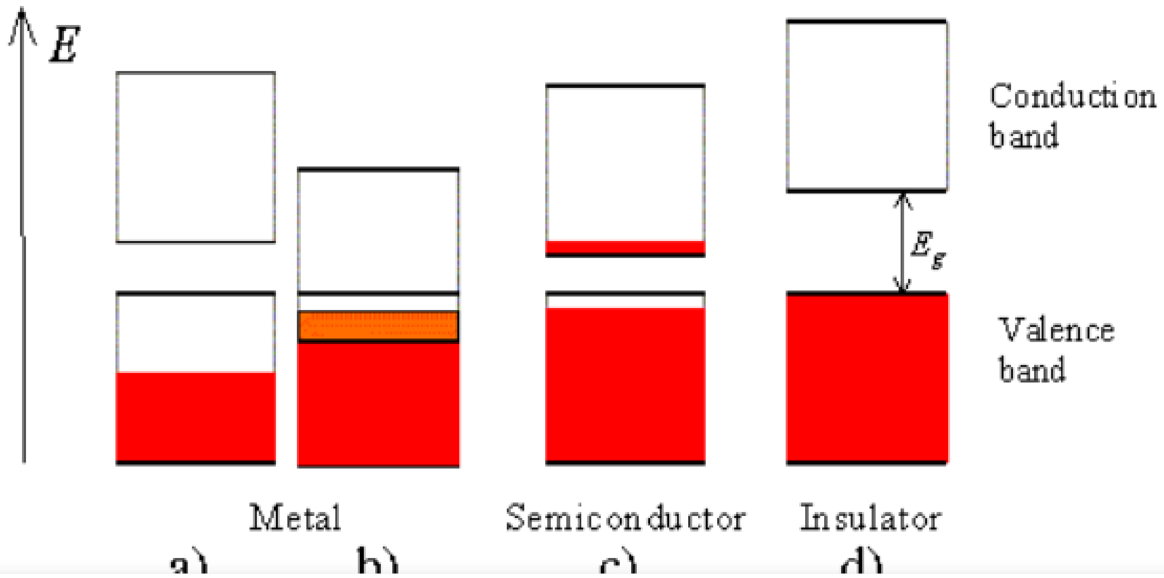


Energy band Diagrams



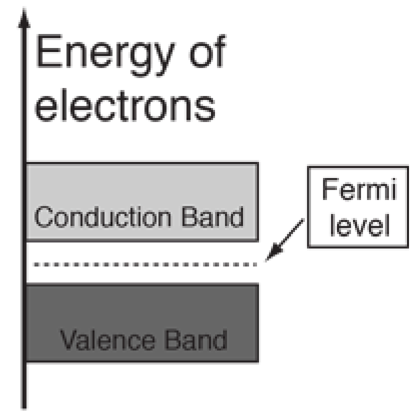
The upper , lower and yellow boxes represent the conduction band, valence band and occupancy level of electrons respectively.

Energy band Diagrams for metals, semiconductors, Insulators



Let's come down to our topic of interest : Semiconductor energy band diagram

- Intrinsic Semiconductors

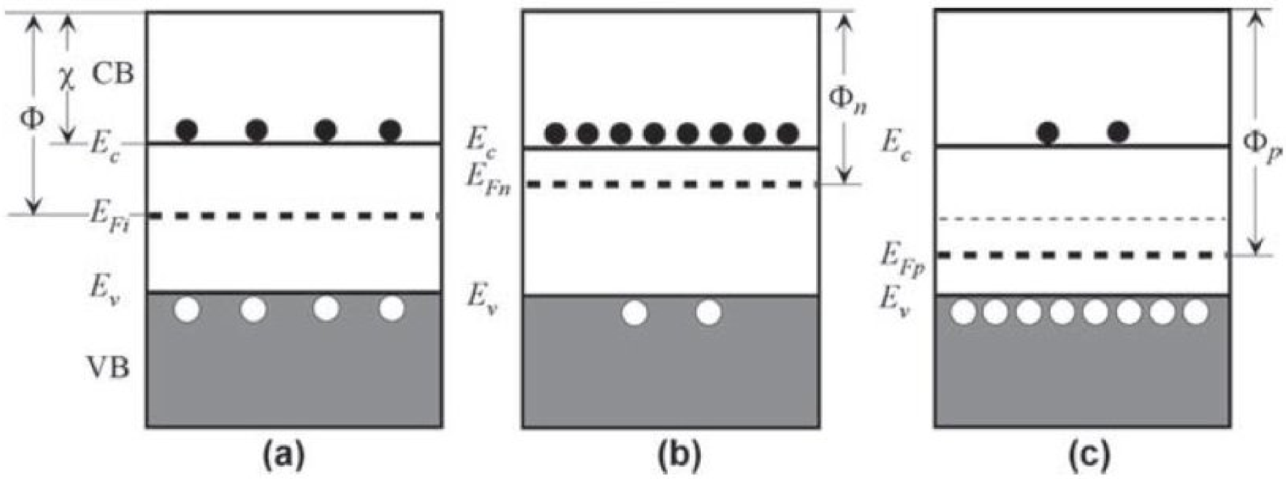


b. Semiconductor

In Intrinsic semiconductors the Fermi energy level is halfway between the valence and conduction bands.

Here we are considering the band diagrams at absolute zero temperature hence there is no conduction , at higher temperatures a finite number of electrons can reach the conduction band and provide some current

- Extrinsic Semiconductor



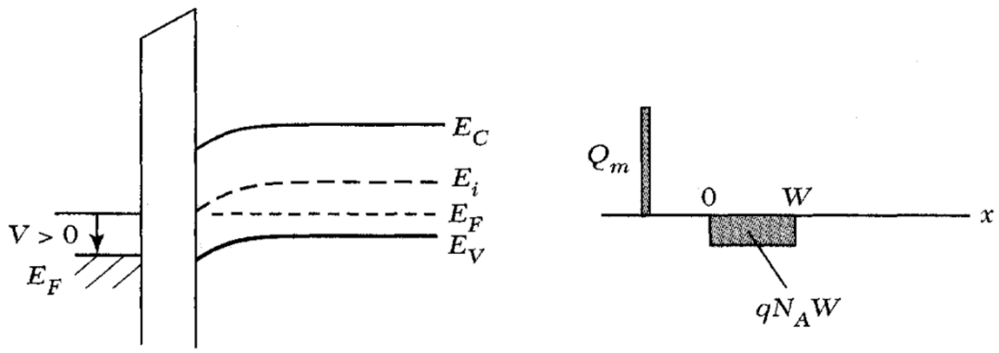
Adding N-type impurity increases the electron density in the conduction band and in

The exact opposite happens when P-type impurity is added i.e as the electron density of conduction band decreases , it requires more energy to excite the electrons to the conduction band. Hence the Fermi Energy level shifts towards the valence band

The shift depends on the extent of doping of impurity.

Fermi energy band diagrams in NMOS

> *Depletion Mode*

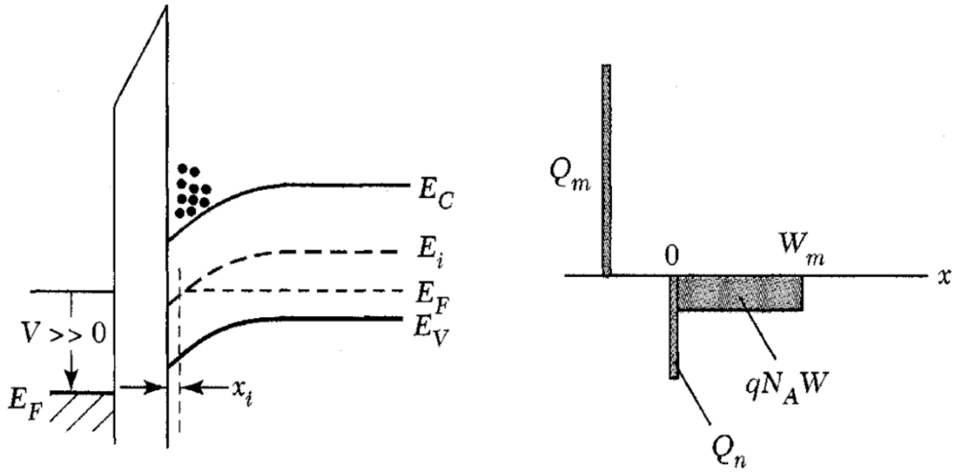


(b)

When a positive gate voltage is applied to a n type MOSFET , holes near the gate oxide and substrate interface are pushed away due to the same charges. Hence there exist no excess holes in the region and net charge there becomes zero. Thus forming a depletion region with all charged particles in pair (electron hole pairs).

Due to the formation of depletion region the intrinsic energy level becomes equal to the fermi energy . The shift in the bands is nearly equal to the gate voltage applied.

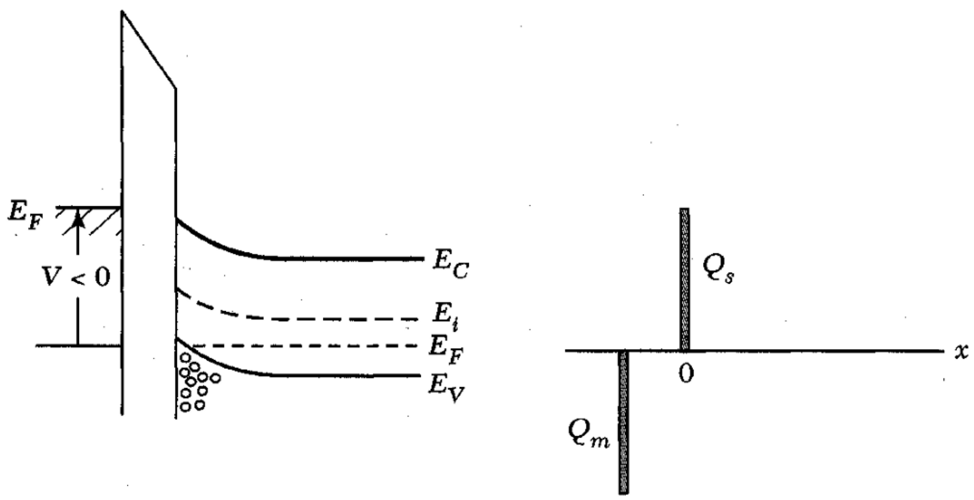
> *Inversion Mode*



When further positive voltage is applied at the gate , free electrons start to get attracted towards the gateocide — substrate interface. Thus near the interface the concentration of n type impurity appears in a p-type substrate. It suggest inversion of the substrate type and so termed as inversion mode.

The intrinsic energy band (Ei) crosses the fermi energy level as Ei lies below Ef for negative doped impurity.

Accumulation Mode



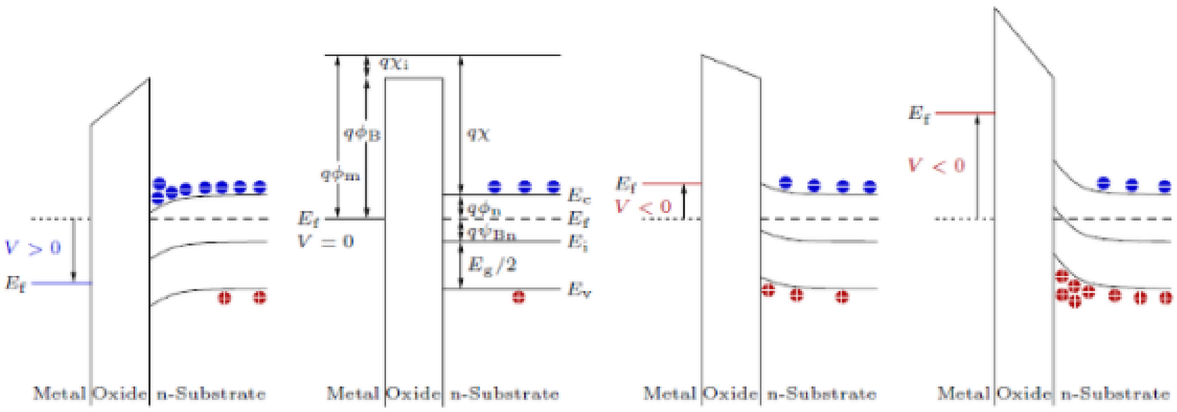
(a)

When negative voltage is applied at the gate terminal of n type MOSFET , a layer of negative charge is formed on the metal gate. This layer attracts the holes in the p-type semiconductor substrate towards the gate oxide — semiconductor interface. Inturn the

Fermi energy band diagrams in PMOS

Modes:

1. Accumulation
2. Turned off
3. Depletion
4. Inversion



1. When a positive voltage is applied at the gate terminal of the p type MOSFET, the opposite charged particles i.e electrons are attracted towards the gate oxide. Due to which there is increase in concentration of majority charge carriers near the oxide. As the doping intensity of n-type particles increase the energy band bends towards the valence band.

2. When there is no gate voltage applied , there is no bending in the fermi energy bands.

3. When a negative voltage is applied at the gate, electrons are repelled away from the region near the gate oxide — semiconductor interface. Hence the net charge near the gate oxide becomes zero. As the concentration of majority charge carrier lowers the intrinsic fermi energy shifts away from the valence band . The band bend upwards.

4. When the negative voltage at gate is increased beyond the threshold voltage , minority charge carriers i.e. holes are attracted near the gate oxide —

the intrinsic fermi energy band crosses the Fermi energy at 0k (Ef) and bends upwards.

Applications Of Fermi Level

1. Fermi Energy levels finds its use in describing properties of metals, insulators and semiconductors.
2. The way fermi energy level depends on factors such as temperature help in determining properties such as conductivity of the semiconductor.

Interesting Research Going On In the field of Fermi Energy

1. Fermi Energy of Optoelectronic Devices
2. Quantum Size Effects in Ultra-thin Films
3. Fermi Energy of Organic Semiconductors

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