Fundamentals of Nanoelectronics

ECE495 - Session 1, August 24, 2009

What Makes Current Flow?

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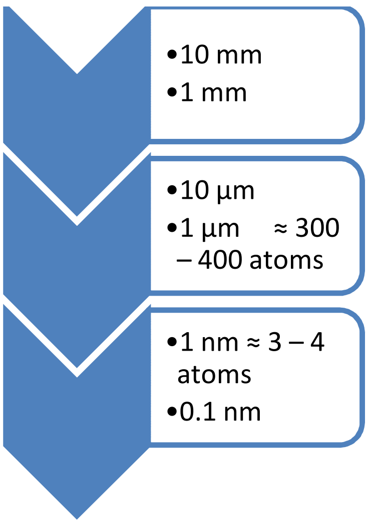
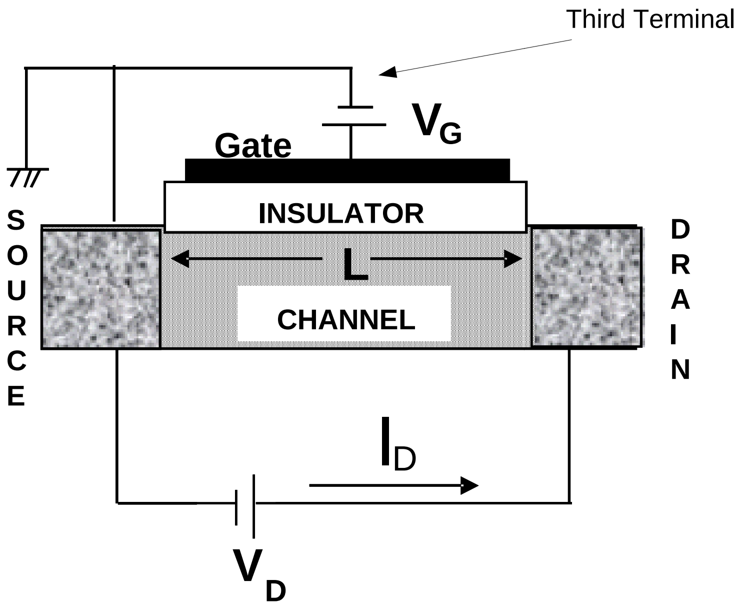
Nanoscale Transistor

Device Length





10 KΩ	→	100 MΩ
ON	→	OFF

A **transistor** is basically a resistance which is controlled by ***third terminal***.

The length of transistor is a approximately 10×L (L is length of channel)

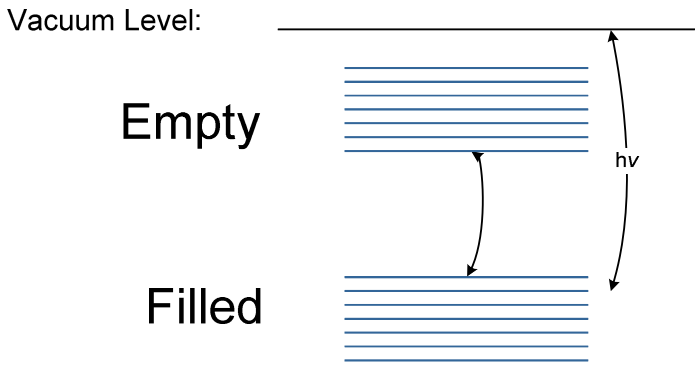
If we apply a voltage on third terminal electron will move. The direction of current is opposite to electron movement direction.

If we assume the device like a capacitor the energy is equal

$E = QV \approx 10^{4}\times10^{-19}\times 1 = 10^{-15}$ J Where charge of electron is ***$q = 1.6 \times 10^{-19}$ coulomb*** and we assumed we have 10^{4} electrons in device and applied voltage is 1V.

Power = $\frac{10^{-15}}{10^{-9}} = 1\mu W$ The change frequency is 1ns (nano sec).

Energy Levels

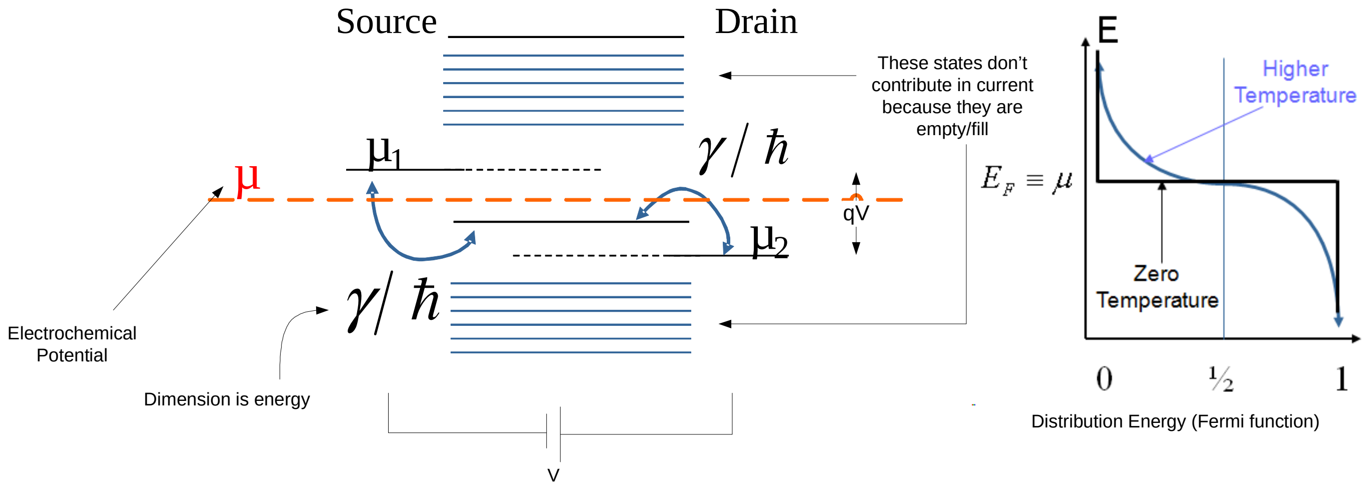


For each material there are energy levels that the electrons could take. Some of these are filled and some are empty.

We can determine the existence of these levels based on photoemission (or photoelectron) effect.

For visible light hν ≈ 2-4eV. For solid we need ≈ 7-8eV.

The vacuum level is the energy (usually used as a reference point) of an electron at rest far from the influence of the potential of the solid (or material).



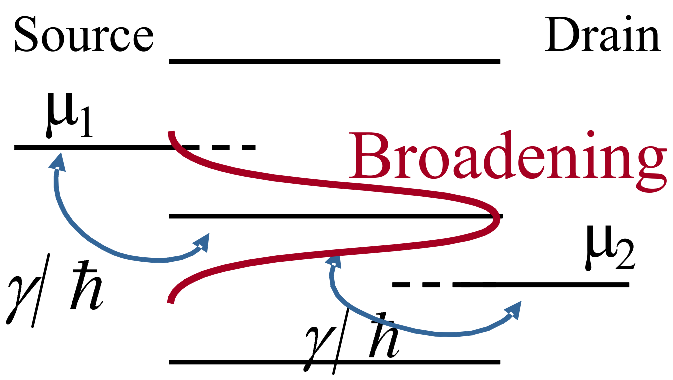
Applying positive voltage would enforce the electrochemical potential to lower level and negative voltage vice versa.

Left side contact likes to fill all states below it and right hand side contact try to empty all states above it then if there are any states between tow potential levels current will starts. The lower states under μ_1 and μ_2 are filled and don't have effect on current.

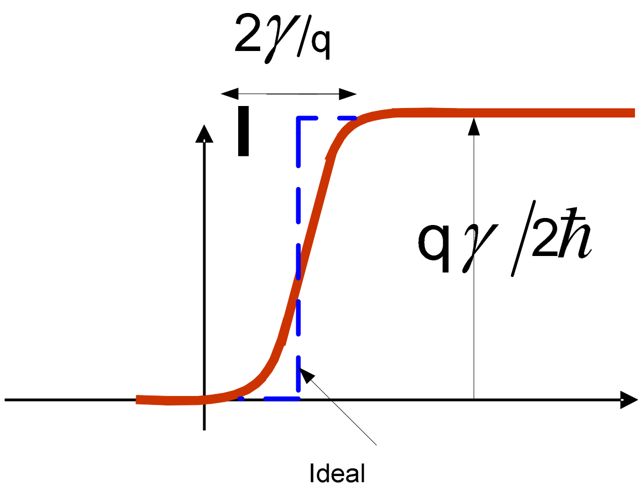
The current is related to how easily electron comes in and out from contacts $(\gamma/\hbar)$ where γ's dimension is energy and $\hbar$ is Planck's constant.

$$\hbar = h/2\pi = 1.06\times10^{-34}\ J\cdot\sec$$

Broadening and I-V characteristic of device



I-V characteristics



Due to ***broadening*** and Fermi function we could not get ideal I-V characteristic. $\frac{dI}{dV}$ is very important for us; The maximum value of it is equal to $\frac{q^2}{\hbar}$.

$$\frac{dI}{dV} = \frac{q\gamma}{2\hbar} \Big/ \frac{2\gamma}{q} = \frac{q^2}{\hbar} \qquad \frac{q^2}{\hbar} = 40\mho = \frac{1}{25K\Omega}$$

Planck's constant is:

$$\hbar = h/2\pi = 1.06\times10^{-34}\,J\cdot\sec$$

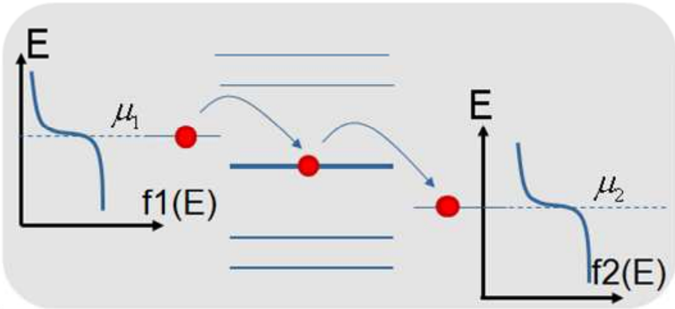
$$R = \frac{V}{I}$$

$$G = \frac{I}{V} \quad ===> \quad G = \frac{\sigma A}{L}$$

Conductivity is $\sigma = \frac{nq^2\tau}{m}$ where τ is mean free time[1], ***m*** is mass of free electron, ***q*** is charge of electron and ***n*** is free electron density. $m = 9.1\times10^{-31}\,Kg$

Diffusive movement is equivalent to Random walk and electron moves with scattering.

In small length channel electron movement is straighter because in mean free time it is long enough to get from left to right. This is ballistic transport. Today, it is ore ballistic because we have 2 or 3 scatterings.



[1] Mean free time is the average time between collisions.