Fundamentals of Nanoelectronics

ECE495 - Session 2, August 26, 2009

Quantum Conductance

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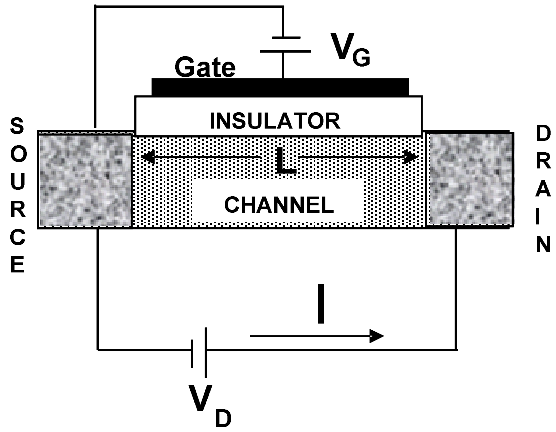
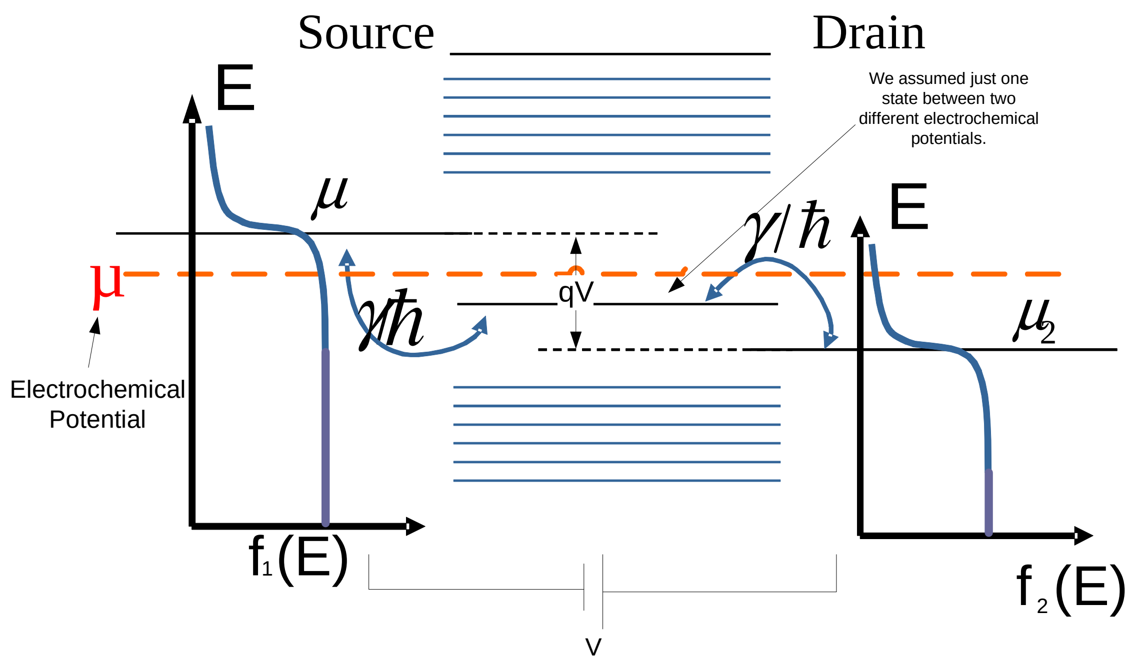
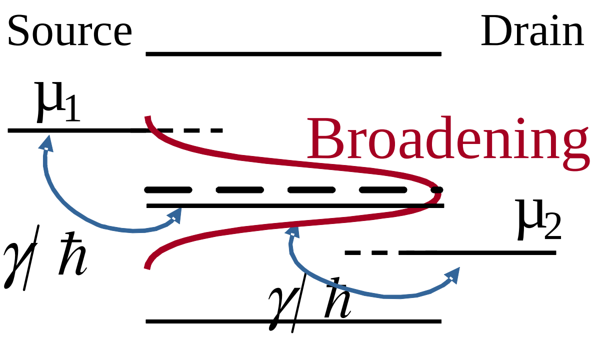
Last Session Review

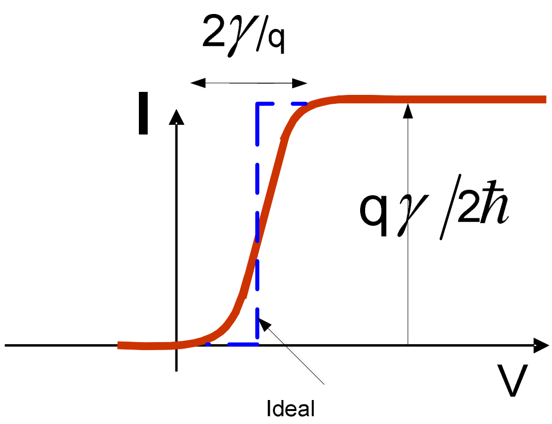


The source of current is the left hand side wants to fill and right hand side wants to empty the energy level between two different electrochemical potentials.



All of energy levels come in pairs (downspin and upspin). Here we assume just one energy level but for bigger devices there are more energy levels.





Example: $\gamma = 1meV$

=> $\frac{\gamma}{\hbar} \approx \frac{1^{-3} \times 10^{-19} \times 1.6\ J}{10^{-34}\ J-sec} \approx 10^{12}/_{sec}$

It means one electron per picoseconds comes in or out.

Coulomb × Volt = Joules

q × Volt = 1ev

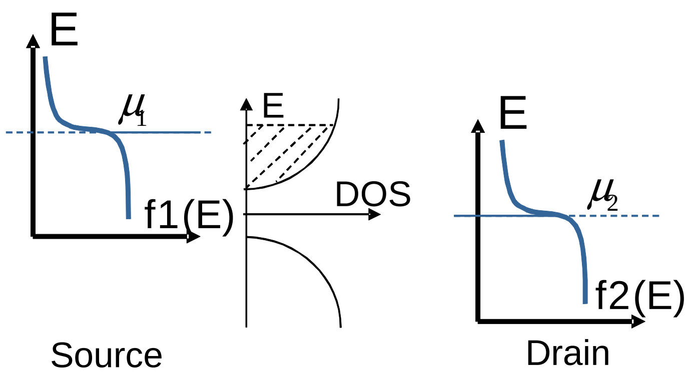
q = 1.6 × 10^{-19} Coulomb

$\hbar = h/_{2\pi} = 1.06 \times 10^{-34}\ J \cdot \mathrm{sec}$

For current calculation, we ignore the levels below/above both electrochemical potentials. The current is related to how easily electron comes in and out from contacts $(\gamma/\hbar)$ and it is actually the rate of electron comes in and out.

Density of states

Density of state (DOS) means how many states per energy unit is available. It is used for more energy levels in bigger devices



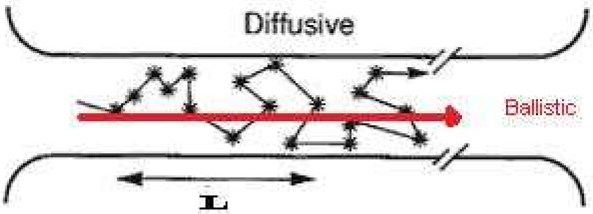
Quantum Conductance

$G = \frac{I}{V} = \frac{q^2}{2\pi\hbar}(\pi\ D\ \gamma)$ D means density of state

The first part, $\frac{q^2}{2\pi\hbar}$ is defined as ***quantum conductance***.

The second part is dependent to material and will not be more than 1.

Ohm's Law



$R = \rho\frac{L}{A} \quad resistance$

$G = \sigma\frac{A}{L}\, conductance\ for\ big\ device$ (I)

$G = \frac{I}{V} = \frac{q^2}{2\pi\hbar}(\pi\, D\, \gamma)$ (II)

Now we want to achieve (I) from (II):

D (Density of state) depends on volume (A×L) in ballistic regime, $t = \frac{L}{v}$ like a bollet which is going stright but for big devices, it is like random walk: $L^2 = (v^2t^2)\frac{t}{\tau}$ where τ is ***mean free time***.

$\gamma = \frac{\hbar}{t}\ \&\, t = \frac{L}{v} \xrightarrow{yields} \gamma = \frac{\hbar v}{L}$ in ballistic

Then, (II) will be equal $G \propto \frac{q^2}{2\pi\hbar}\left(\pi\, A \times L\, \frac{\hbar v}{L}\right) \propto \frac{q^2}{2\pi\hbar}(\pi\, A\, \hbar v)$ for ballistic regime.

In ballistic if length of device increases two times current would be the same.

$\gamma = \frac{\hbar}{t} = \frac{\hbar v^2\tau}{L^2} = \frac{\hbar v}{L}\frac{v\tau}{L} \quad v\tau = \lambda\, (\boldsymbol{mean\ free\ path}) = \frac{\hbar v}{L}\frac{\lambda}{L}\ but\ it\ is\ actally\ \frac{\hbar v}{L}\frac{\lambda}{L+\lambda}$ in diffusive

Then, (II) will be equal $G \propto \frac{q^2}{2\pi\hbar}\left(\pi\, A \times L\, \frac{\hbar v}{L}\frac{v\tau}{L}\right) \propto \frac{q^2}{2\pi\hbar}\left(\pi\, A\, \hbar v\, \frac{\lambda}{L}\right)$ for diffusive regime.

$G = \frac{I}{V} = \frac{q^2}{2\pi\hbar}(\pi\, D\, \gamma) = 2 \times \frac{q^2}{2\pi\hbar} \times \pi\, D\frac{\hbar v}{L} \times \frac{\lambda}{L+\lambda}$ the last part is for long devices (diffusive movement) and in ballistic devices it would be omitted. Also, 2 is multiplied due to spin.

$M \triangleq \pi\, D\frac{\hbar v}{L}$ is number of modes which means how many channels we have between chemical potentials.

$R = \frac{\hbar}{2q^2M}\left[\frac{L}{\lambda} + 1\right]$ for long device R is linearly increased with L but for ballistic term, $\frac{L}{\lambda}$, would be removed.

$R = \rho\frac{L}{A} = \rho\frac{\lambda}{A}.\frac{L}{\lambda}$ and $I = \frac{q\gamma}{2\hbar}D\, q\, V$ if Fermi function be very sharp like in low temperature.