

Fundamentals of Nanoelectronics

ECE495 - Session 3, August 28, 2009

Current

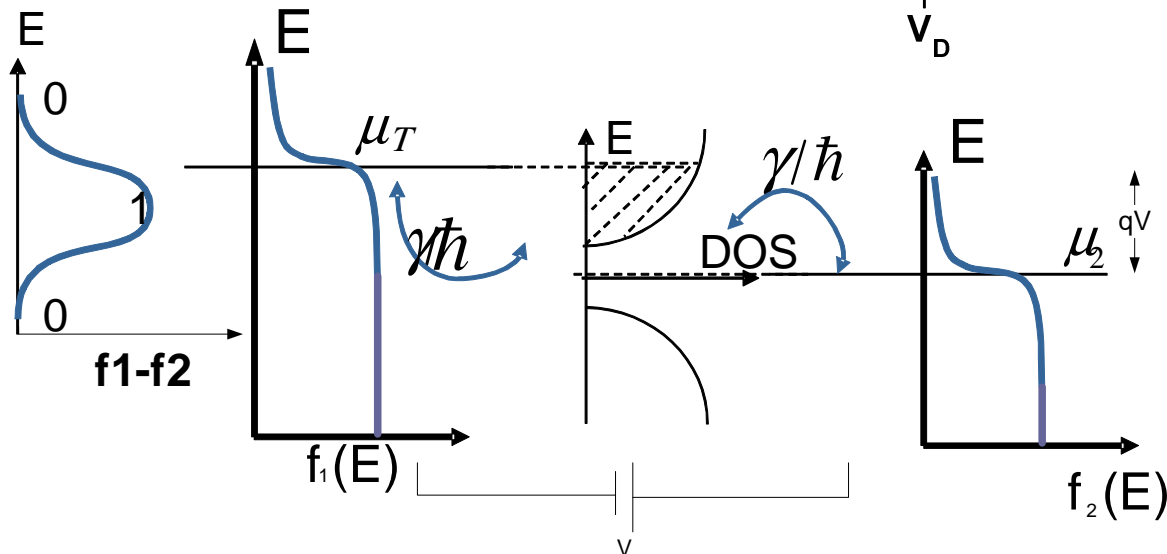
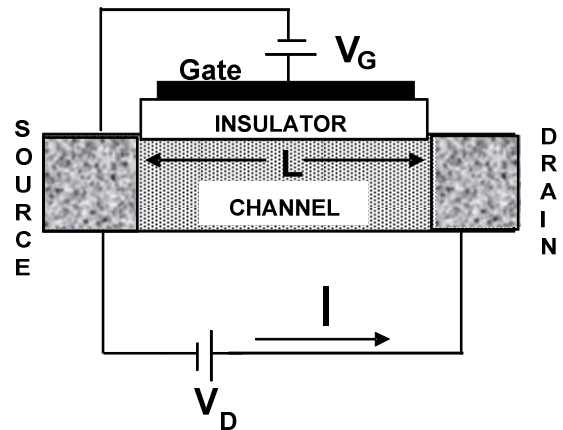
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Current Calculation

$$I = 2 \frac{q}{\hbar} \int dE D(E) \frac{\gamma}{2} (f_1 - f_2)$$

Density of state (DOS), $D(E)$ tells us how many states are at a specific energy per energy unit. So $dE \cdot D(E)$ tells how many states we have.



Why we have current flow? Because the two contacts are held at different electrochemical potentials (μ_1 and μ_2), which defines the Fermi functions. Left contact wants to fill and the right contact wants to make it empty.

Current flows if there is difference between the f_1 and f_2 . If we apply voltage V_D then $\mu_1 \neq \mu_2$ then $f_1 \neq f_2$. In addition if $V_D = 0 \Rightarrow \mu_1 = \mu_2$ but there is temperature difference current might flow. This is called thermoelectric current.

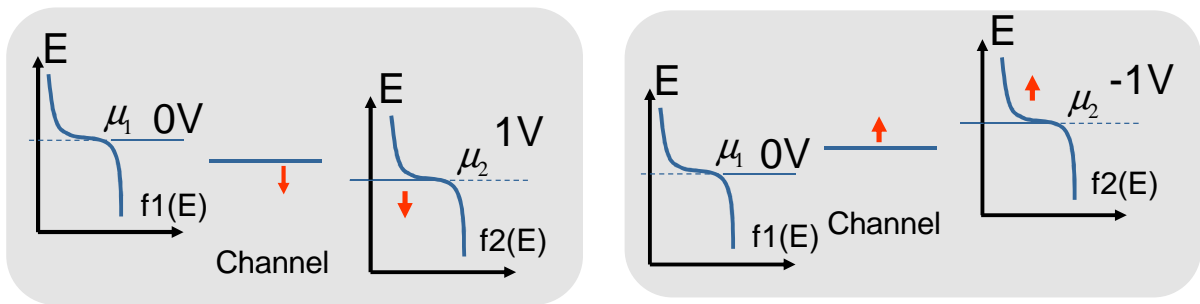
$I = \frac{q\gamma}{2\hbar} D qV$ while $\frac{q\gamma}{2\hbar}$ is current for one level, qV is energy range we are interested in and DqV is number of levels.

$I = 2 \frac{q}{\hbar} \int dE D(E-U) \frac{\gamma}{2} (f_1 - f_2)$ dE will change to ΔE for calculation in MatLab and we will assume many small fraction in E axis (energy grid with $\Delta E \approx 1\text{meV}$) in $D(E)$ formula then we change the integral to summation to calculate current.

We will think of this “2” as representing the two spins (upspin and downspin). When we compute the DOS, we usually include a factor of 2 for spin. $D/2$ is the DOS per spin.

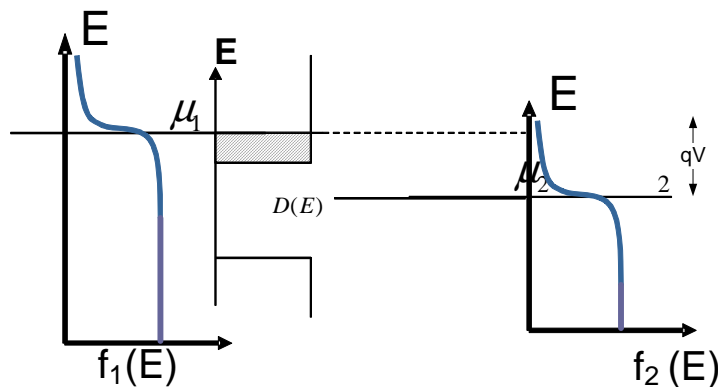
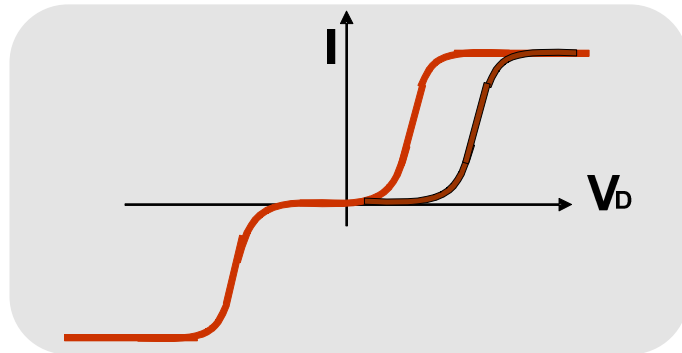
$$G = \frac{I}{V} = \frac{q^2}{2\hbar} D \gamma$$

As the pictures illustrate the channel energy levels move up and down with the drain levels (source is kept fixed as a reference). The sense of movement depends on the sign of the applied voltage. The speed of movement for channel is half.

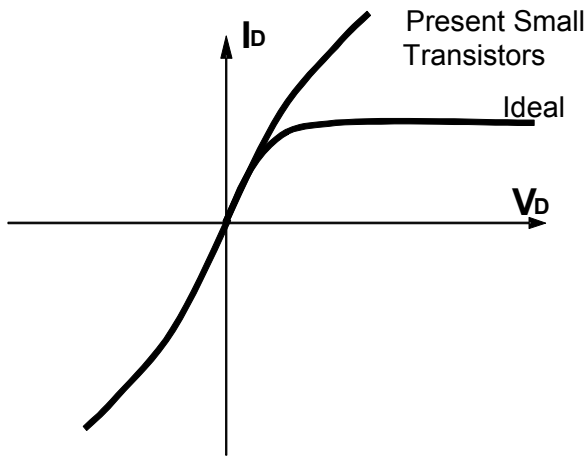


$$\mu_1 = \mu_2 - qV = \mu + U_{\text{drain}}$$

I-V characteristics for the device:



Now we assume we have a material with DOS like this one in the figure. How does the I-V curve look like?

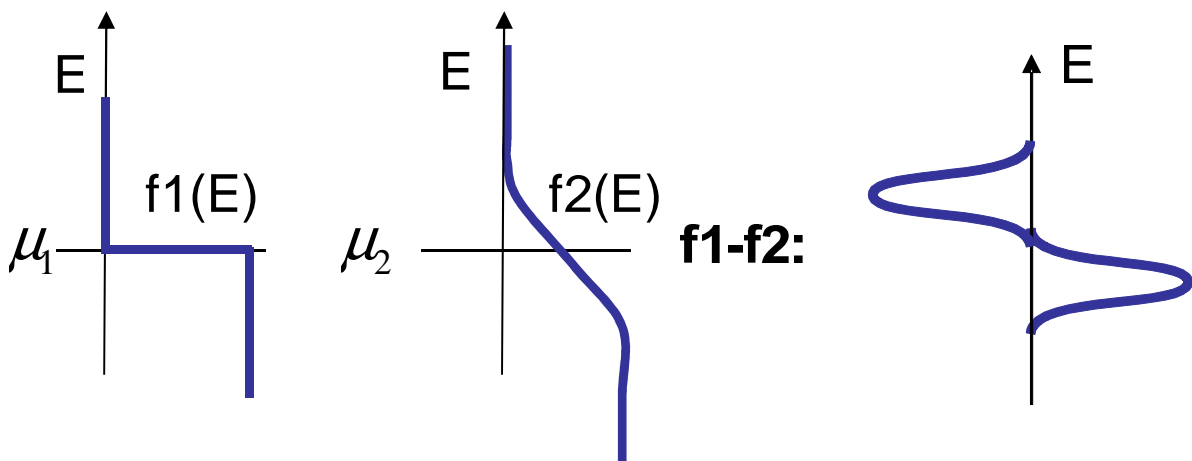


This is exactly what we want from a good transistor from the circuit point of view. But in small transistors what people get is that current keeps increasing. The reason is that as the drain levels are lowered, the DOS in the channel also wants to slide down.

$$I = 2 \frac{q}{\hbar} \int dE D(E-U) \frac{\gamma}{2} (f_1 - f_2)$$

$$f(E) = \frac{1}{(e^{(E-\mu)/k_B T} + 1)}$$

What happens if we don't apply a voltage but make one contact warmer than the other one?



Under these conditions the two electrochemical potentials are at the same energy. But because f_2 changes smoothly and f_1 doesn't, $f_1 - f_2$ is not 0 for all energy ranges and this results in a current flow. In this situation, we will get current if density of states be zero above μ and positive under μ . In n-type and p-type the current direction is different and based on this test we could detect the type of transistor.