

ECE 495N

Fundamentals of Nanoelectronics

Fall 2008

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Lecture: 6

**Title: Quantitative Model for Nanodevices III
Date: September 8, 2008**

**Video Lectures posted at:
<https://www.nanohub.org/resources/5346/>**

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Quantitative
Model for
P-nanodevices III

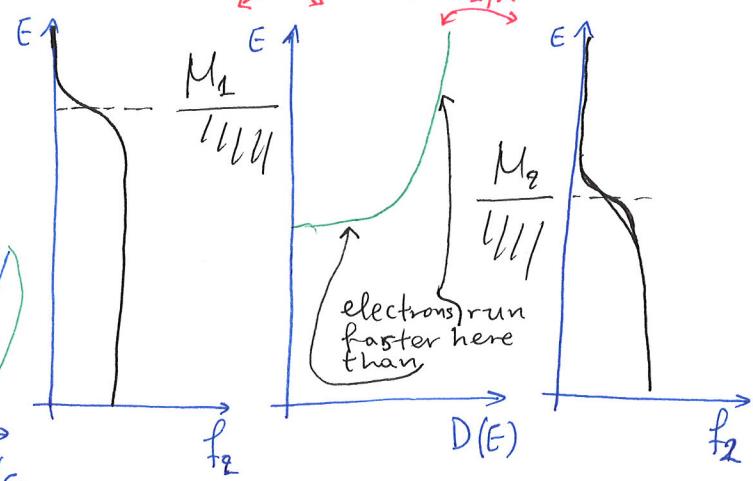
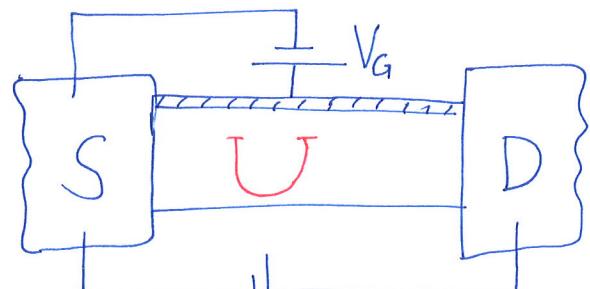
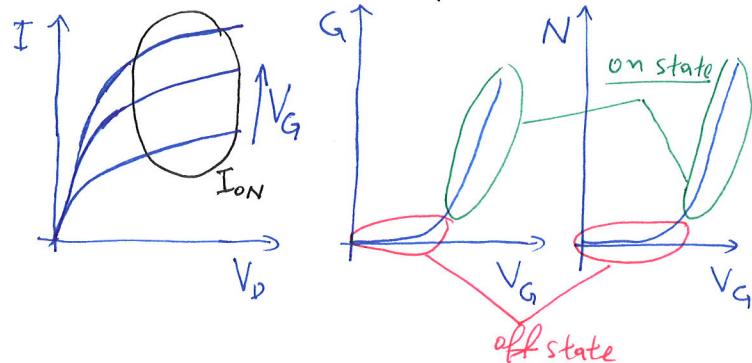
Lecture 6

Sept. 08, 2008

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

$$N = \int dE \cdot D(E-U) \frac{f_1 + f_2}{q}$$

$$U = U_L + U_o (N - N_o)$$



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

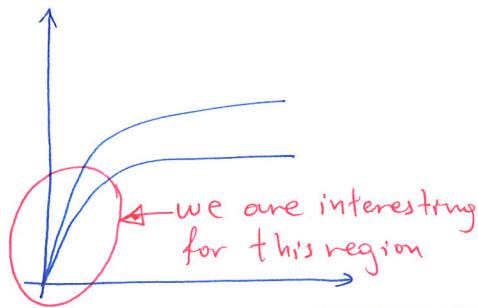
$$N = \int dE D(E-U) \frac{f_1}{q}$$

$$I_{ON} \approx q \frac{\gamma}{\hbar} N$$

and $\frac{\gamma}{\hbar} = \begin{cases} \frac{V}{L}, & \text{ballistic transport} \\ \frac{V}{L} * \frac{\lambda}{\lambda+L}, & \text{mean free path, diffusive transport} \end{cases}$

For I_{ON} we have set $f_0 = 0$ and that the velocity is independent of energy

For the linear region we are assuming that μ_1 and μ_2 are close enough.



$$\text{Also } f_1 \approx f_2 = f$$

$$\text{Then } I = q \int dE \cdot D(E-U) \frac{\gamma}{2\pi} \cdot \left(-\frac{\partial f}{\partial E} \right) \underbrace{(\mu_1 - \mu_2)}_{qV_D}$$

Conductance

$$\Rightarrow G = \frac{I}{V} = q^2 \int dE \cdot D(E-U) \frac{\gamma}{2\pi} \left(-\frac{\partial f}{\partial E} \right)$$

$$N = \int dE \cdot D(E-U) f(E)$$

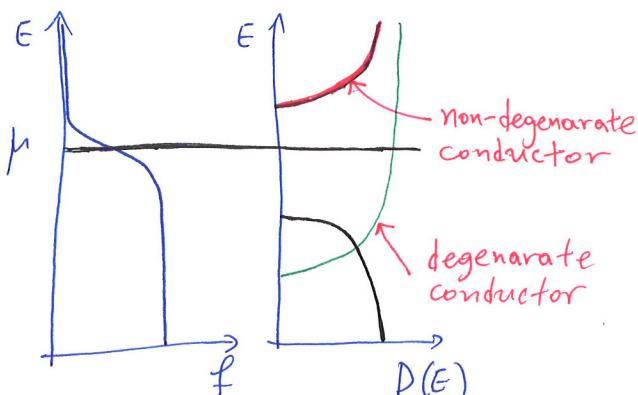
conductance depends on the change of the fermi function

number of electrons depends on the fermi function

$$\text{So, } G = q^2 \int dE \cdot D(E-U) \frac{\gamma}{2\pi} \frac{f(1-f)}{kT}$$

NOTE 3

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



NOTE 1

$$f_1 = \frac{1}{1 + e^{(E-\mu_1)/kT}}$$
Slope

$$f_2 = \frac{1}{1 + e^{(E-\mu_2)/kT}}$$
Slope

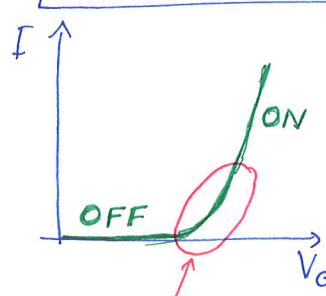
$$f = \frac{1}{1 + e^{(E-\mu)/kT}}$$
Slope

$$\Rightarrow f_1 - f_2 \approx \left(-\frac{\partial f}{\partial E} \right) (\mu_1 - \mu_2)$$

NOTE 2

$$f(x) = \frac{1}{e^x + 1}$$

$$f'(x) = -\frac{e^x}{(e^x + 1)^2} = -\frac{1}{e^x + 1} \cdot \frac{e^x}{e^x + 1}$$



We saw expressions (using simplification) for the ON and OFF states. For the intermediate region we have to use full expression for the current and a numerical program to solve it.

— The next question that we have to answer is what gate voltage (how much gate voltage) should we apply to turn off the transistor?

$$f = \frac{1}{1 + e^{(E-f)/kT}} \stackrel{*}{=} e^{-(E-f)/kT}$$

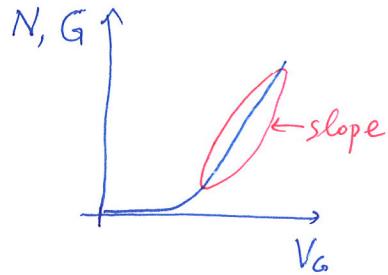
* if all the interest energies are bigger than μ .

This means that $G, N \sim e^{-\underline{(E-U-\mu)/kT}}$ and describes only the off state

It's supposed that the DOS are fixed.

If I will change U by $kT = 25\text{meV}$ then G and N will go down of a factor e^{-1} . [factor of 10: $2.3kT = 60\text{meV}$]

— The next question is which is the slope in the ON state?



$$N = D_0(\mu - U)$$

$$\Rightarrow \Delta N = -D_0 \cdot \Delta U = -q \Delta V_G \cdot D_0$$

$$\Rightarrow \boxed{\Delta Q = -q \Delta N = q^2 \cdot D_0 \cdot \Delta V_G}$$

This is not absolutely correct because we have to solve for U self-consistently. U depends on N

C_Q : quantum conductance

$$\Rightarrow \frac{\Delta Q}{\Delta V_G} = \frac{C_Q C}{C_Q + C}, \text{ where } U_0 = \frac{q^2}{C} \text{ and } C_Q = q^2 D_0$$



depends on electrostatics

depends on density of states