ECE 495N

Fundamentals of Nanoelectronics

Fall 2008

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Lecture: 5
Title: Quantitative Model for Nanodevices II
Date: September 5, 2008

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

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Quantitative Model for Nanodevices II

Lecture 5

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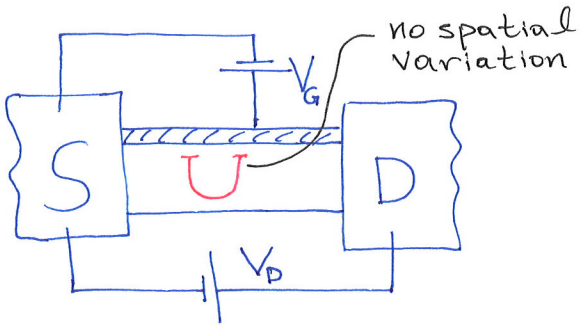
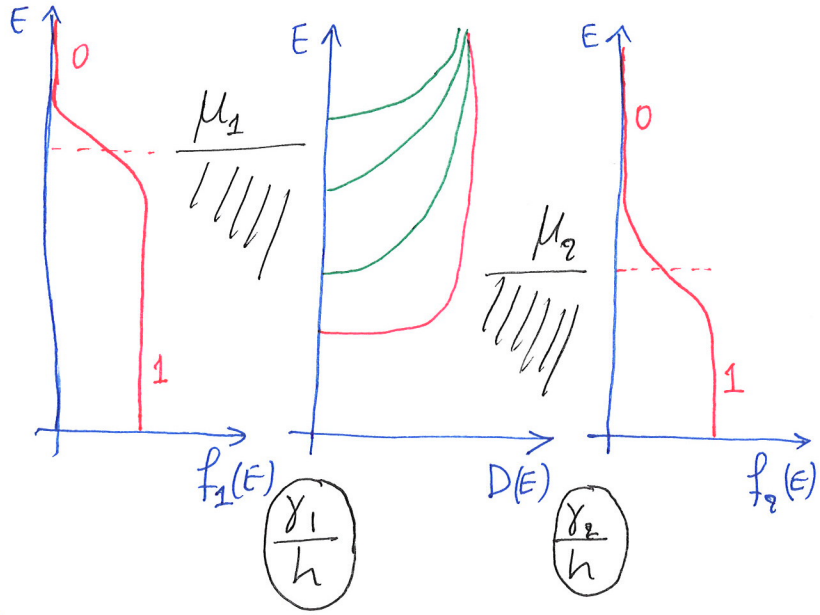
$$I = \frac{q}{\hbar}\int dE \cdot D(E-U)\,\frac{\gamma_1\gamma_2}{\gamma_1+\gamma_2}\left[f_1(E)-f_2(E)\right]$$

self-consistent calculation

$$N = \int dE \cdot D(E-U)\,\frac{\gamma_1 f_1 + \gamma_2 f_2}{\gamma_1+\gamma_2}$$

$$U = U_L + U_0(N - N_{eq})$$





- If $U_0 = 0$ then $U = U_L \neq f(N)$ and hence these two equations are decoupled.
- Intuition solution of the above system.
- Two contact voltages with two different roles:
  $V_D \rightarrow$ drives the current between D and S.
  $V_G \rightarrow$ allow us to control that current.

Important parameters: $D(E)$, γ_1, γ_2

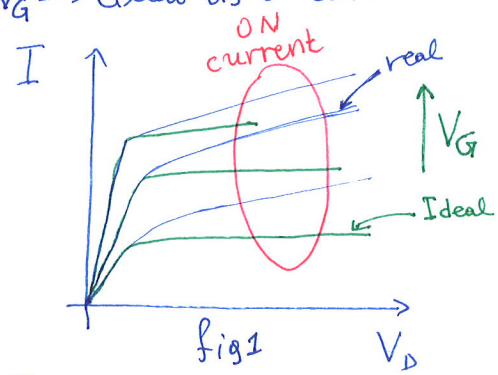


fig 1

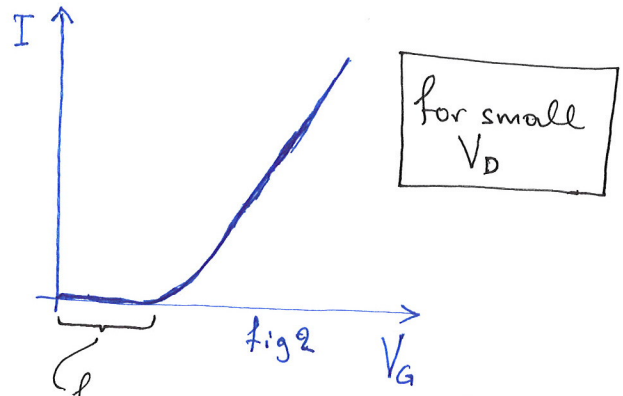


fig 2

for small and negative V_G the energy window between μ_1 and μ_2 does not contain DOS which are pulled up out of this window.

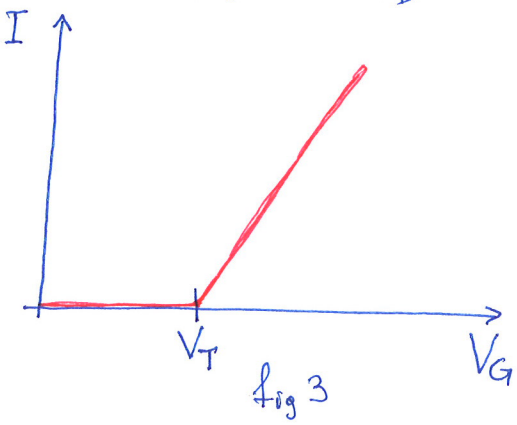


fig 3

If V_D is very small then $\mu_1 \cong \mu_2 \Rightarrow f_1 \cong f_2$ and hence $N = \int dE \cdot D(E-U) f_1(E)$

1 mm

BETWEET

$\gamma = \frac{\hbar v}{L} * \frac{\Lambda}{\Lambda + L}$

1 μm

← diffusive transport

$\hookrightarrow \gamma = \frac{\hbar v}{L} \cdot \frac{\Lambda}{L}$

← ballistic transport

$\hookrightarrow \gamma = \frac{\hbar v}{L}$

1 nm ← atomic scale

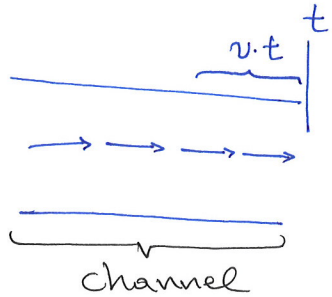
← wave nature (solution of S.E)

$$i_1 = \frac{q}{\hbar} \int dE \cdot D(E-U)\, \gamma_1 \overbrace{(f_1 - f)}^{=1}$$

$$i_2 = \frac{q}{\hbar} \int dE \cdot D(E-U)\, \gamma_2 \overbrace{(f - f_2)}^{=0}$$

$$i = q \frac{\gamma}{\hbar} N$$

Ballistic Case

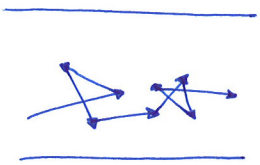


$$i = \frac{N}{L} v \cdot q$$

$$\Downarrow$$

$$\frac{\gamma}{\hbar} = \frac{v}{L}$$

Dissusive Case



$(v \cdot \tau) = \Lambda$ ← mean free path

$\frac{t}{\tau}$ ← number of scattering's

$$\frac{t}{\tau} \cdot (v\tau)^2 = L^2$$

$$\Rightarrow \frac{1}{t} = \frac{1}{L^2} v^2 \tau = \frac{v}{L} \cdot \frac{v \cdot \tau}{L}$$

If now we write the "γ" as

$$\gamma = \frac{\hbar v}{L} * \frac{\Lambda}{\Lambda + L}$$

then it's like interpolation between diffusive and ballistic.

Let's check it: • if $L \ll \Lambda$

then $\frac{\Lambda}{\Lambda + L} \approx 1 \Rightarrow \gamma = \frac{\hbar v}{L} \Rightarrow$ ballistic

• if $L \gg \Lambda \Rightarrow \frac{\Lambda}{\Lambda + L} \approx \frac{\Lambda}{L} \Rightarrow$

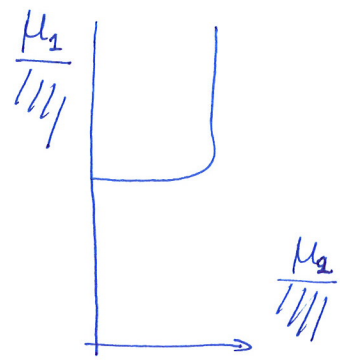
$\Rightarrow \gamma = \frac{\hbar v}{L} \frac{\Lambda}{L} \Rightarrow$ diffusive

I_{ON} (very high V_D)

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

$$N = \int dE \cdot D(E-U) \frac{f_1(E)}{2}$$

$$\Rightarrow I_{ON} = N q \frac{\gamma}{\hbar}$$



oxide capacitance per unit area

$$\xrightarrow[\text{limit}]{\text{ballistic}} I_{ON} = q N \frac{v}{L} = W \cdot L\, C_{ox} (V_G - V_T) \frac{v}{L}$$

$N \approx (V_G - V_T)$ see fig 3

$$\Rightarrow \boxed{I_{ON} = W C_{ox} (V_G - V_T) v} \Rightarrow I'_{ON} = C_{ox} (V_G - V_T) v$$

on current per unit length

classical capacitor

$$C = \frac{\epsilon A}{d}$$

area of the plates

distance between plates

quantum capacitance

$$C_Q \sim q^2 D$$

density of states

- If we have a channel with <u>low</u> density of states then C_Q in the important capacitance, if the density of states is <u>high</u> then C is important.
- for very small conductor (in our days) C_Q should be taken into account.