Fundamentals of Nanoelectronics

ECE495 - Session 5, Sept 2, 2009

I-V characteristics

Ref: Chapters 1.3 and 1.4

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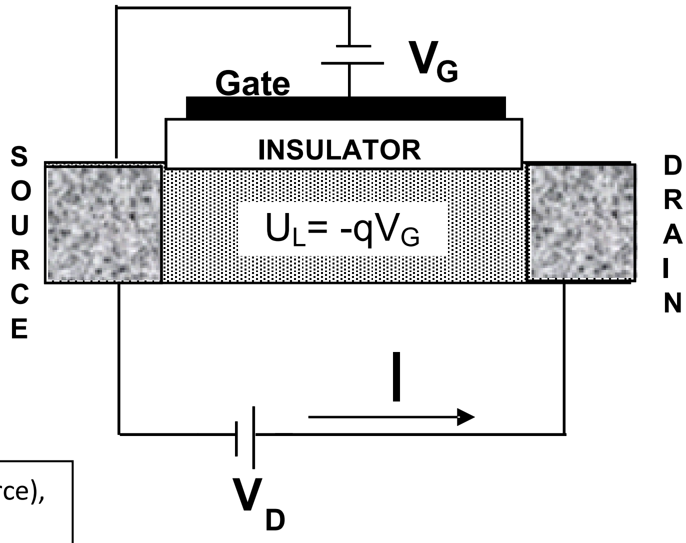
Review

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

$$N = \int dE D(E-U) \frac{f_1(E) + f_2(E)}{2} \quad (II)$$

$$U = U_L + U_0(N - N_0) \quad (III)$$

If $U_0 = 0 \Rightarrow U = U_L \neq f(N)$ then these two equations are decoupled.

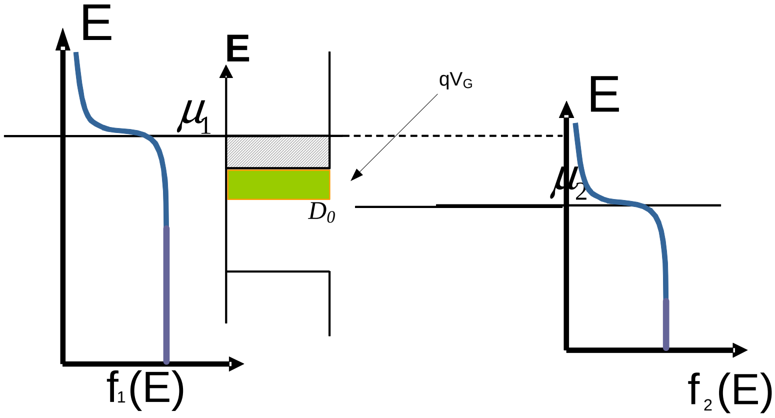


V_D: Drives the current between D(Drain) and S(Source),

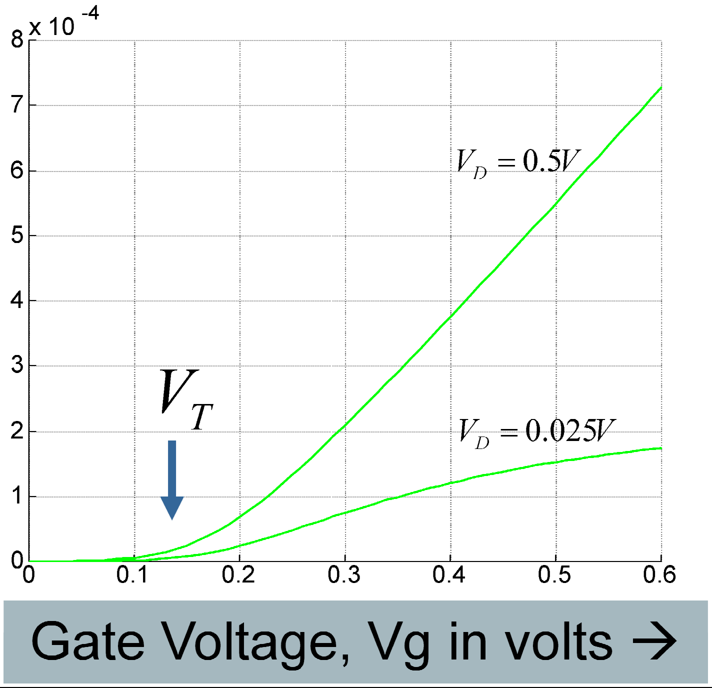
V_G: allows us to control that current.

Important parameters:

D(E) and γ_1, γ_2



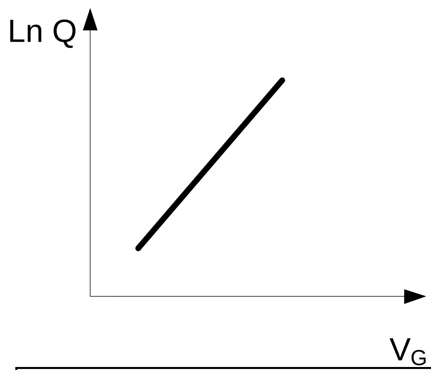
I-V characteristic and



The vertical Axis is current I and it could be assumed like Q.

$Q = CV \Rightarrow Q = C(V_G - V_T)$

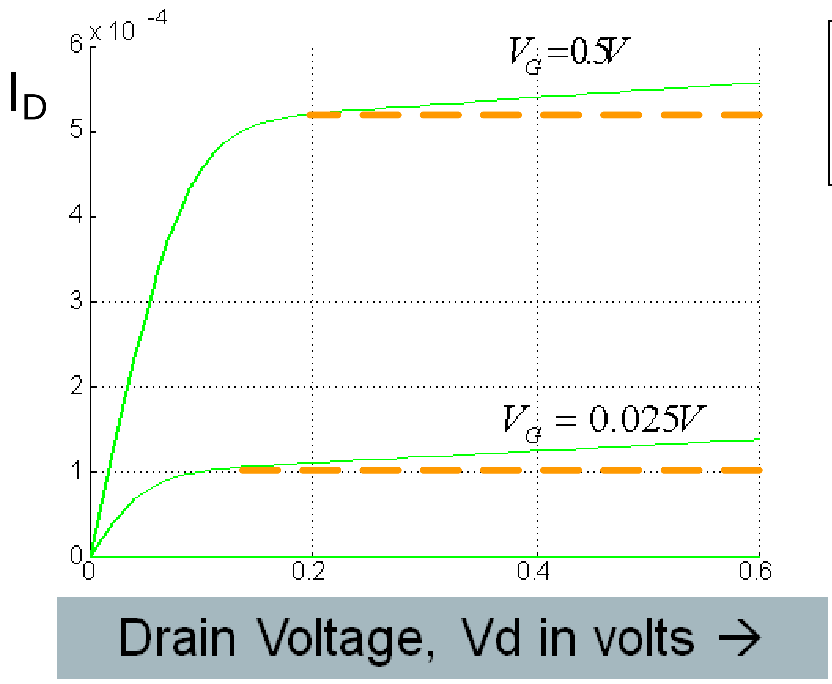
This is for small V_D.



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.

If we draw a logarithmic plot for $V_G < V_T$ the plot will be like above figure.

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



Dotted lines show the ideal I-V characteristic. The continuous lines show the real I-V.

Capacitors

$q\delta N = D_0 (q^2 \delta N) - U_0 \delta N$ first part is for U_L and second part is for $U_0(N-N_0)$

$\delta Q = (q^2 D_0)\delta V_G$

$C = q^2 D_0 F$ = Coulomb^2 /Joules

=> $\delta N = 1 + D_0 U_0 = D_0 q \delta V_G$

$\delta Q = \delta V_G\, \mathbf{q^2 D_0}/(1+U_0 D_0) \approx \delta V_G\, q^2/U_0 = \delta V_G\, C_E$

$C_E \propto \frac{\varepsilon A}{t_{ox}}$ $q^2 D_0$: quantum capacitance

$U_0 = q^2/C_E$ E stands on electrostatic

$$\frac{1}{C_{eff}} = \frac{\delta V_G}{\delta Q} \quad \& \quad \delta V_G = \delta Q.\frac{1}{q^2 D_0} + \frac{U_0 D_0}{q^2 D_0} \quad \& \quad \frac{U_0}{q^2} = \frac{1}{C_E} \quad \& \quad \frac{1}{q^2 D_0} = \frac{1}{C_Q} \xrightarrow{yields} \frac{1}{C_{eff}} = \frac{1}{C_Q} + \frac{1}{C_E}$$

This equation shows which capacitance is smaller has more effect. In smaller device C_Q is more important.

When $V_G < V_T$, C_Q is really small and very important we are worry about $U_0(N-N_0)$.

$$N = 2\int dE D(E-U) f_0(E)$$ Here, if we shift f(E) is better than shift in D(E)

$$U = U_L$$

$$\Rightarrow N = 2\int dE' D(E') f_0(E'+U)$$

$$f_0(E) = \frac{1}{1 + e^{\frac{E-\mu}{kT}}} \approx e^{-(E-\mu)/kT} \; Boltzman\ Approximation$$

$$\Rightarrow N = 2\int dE' D(E')\, e^{-(E'+U-\mu)/kT}$$

We can get out $e^{-U/kT}$ from integral

$N \sim e^{-U/kT} \sim e^{\frac{qV_G}{kT}}$

$$Q \sim e^{\frac{qV_G}{kT}} Q_0 \xrightarrow{yields} Ln\, Q = Ln\, Q_0 + \frac{qV_G}{kT} \Rightarrow V_G = \frac{kT}{q}(Ln\, Q - Ln\, Q_0)$$

Subthreshold swing: The voltage required to increase or reduce I_D (or Q) by one decade

$$Ln\, 10 \times \frac{kT}{q} \cong 60mV$$