

6.701/6.719 Introduction to Nanoelectronics

Final Exam

May 17nd 2010

Time 3 hours

Name: _____

Instructions

Please answer all four questions. Show your working in the space provided.
6.701 students do not need to answer Q2(d).

Some constants

$$\hbar = 1.055 \times 10^{-34} \text{ Js}$$

$$q = 1.6 \times 10^{-19} \text{ Coloumbs}$$

$$m = 9.1 \times 10^{-31} \text{ kg}$$

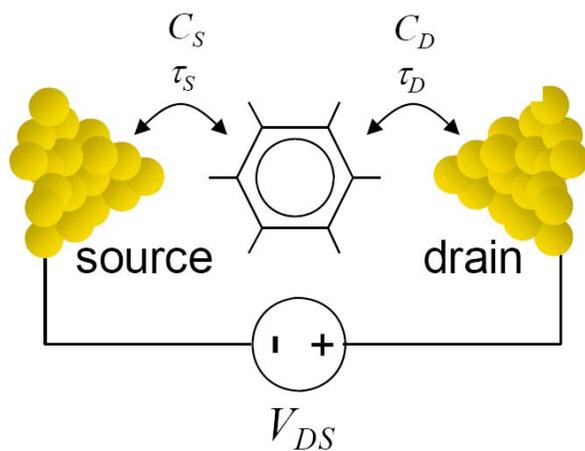
Charge on an electron

Mass of an electron

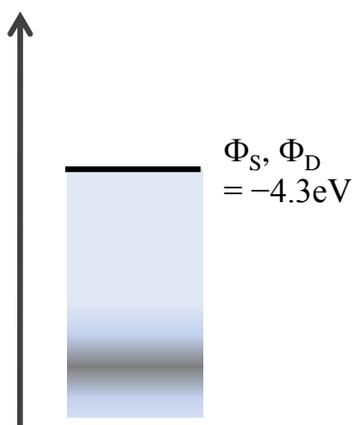
Question 1. Singlet molecule two-terminal device (30 points)

Consider the following single molecule device.

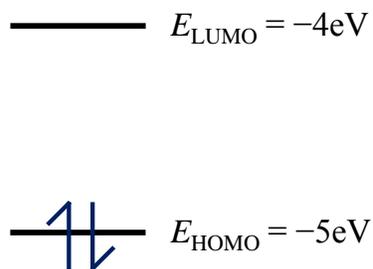
$$T = 0\text{K}$$



Source and Drain
Contacts



Molecule (Isolated)
Density of States



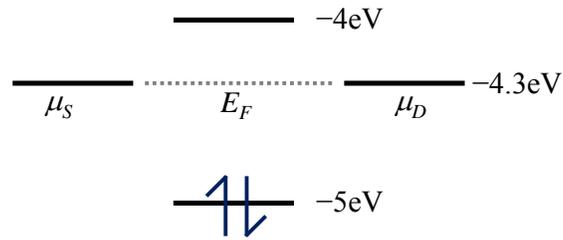
(a) When $\tau_s = 1$ fs, $\tau_D = 2$ fs, calculate the actual molecular density of states versus energy. Determine the full width half maximum of HOMO and LUMO.

(b) Based on the actual density of states calculated in (b), find the number of electrons and the charging energy when the molecule is brought into contact with the metal electrode and reached equilibrium (applied voltage = 0). Also sketch the energy diagram at equilibrium. Assume that the charging energy per electron is 1eV and $\tau_s = 1$ fs, $\tau_D = 2$ fs .

Hint: You might use $\int \frac{1}{1+x^2} dx = \tan^{-1}(x)$. You will need your calculator to solve this. You can calculate down to the precision of ± 0.1 eV.

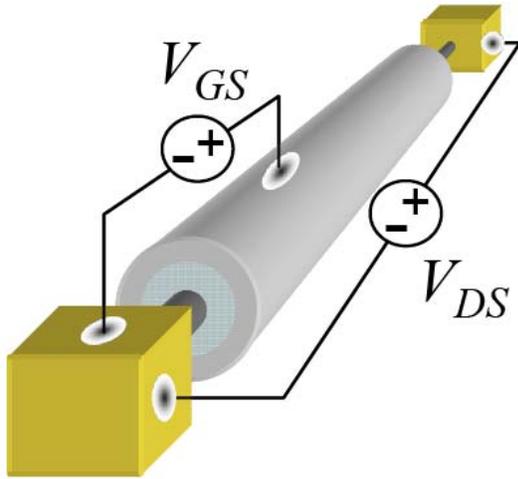
(c) When $\tau_S = \tau_D = 1$ ns, calculate the $I_{DS}-V_{DS}$ characteristics for positive V_{DS} and sketch it. .
 Assume that the charging energy per an electron is 0.1eV and C_S and C_D are identical.

Assume that at equilibrium,



Question 2. Ballistic quantum wire FET (30 points)

Consider the following quantum wire FET.



Assume that the quantum wire is made of either 1) Si or 2) GaAs. The effective masses of Si and GaAs are $0.98 \cdot m_0$ and $0.067 \cdot m_0$, respectively. The electron mass m_0 is $9.1 \cdot 10^{-31}$ kg. The conduction band edge is at $E_C = -5.0$ eV, and the source and drain work functions are $\Phi_S = \Phi_D = -4.5$ eV. The widths of wires are $L_x = L_y = 1$ nm. Assume that C_S and C_D are equivalent.

(a) Sketch the dispersion relations for both Si and GaAs quantum wires for the first 3 modes. Describe the main differences.

(b) Calculate the current–voltage (I_{DS} – V_{DS}) characteristics for $0 < V_{DS} < 1\text{V}$ for both Si and GaAs quantum wires and sketch them.

(c) Calculate the current–voltage (I_{DS} – V_{DS}) characteristics for $0 < V_{DS} < 2\text{V}$ as a function of V_G of -1V , 0V , and 1V for the Si quantum wire FET and sketch them. Assume that $C_G \gg C_S, C_D$ and ignore the quantum capacitance.

(d) 6.719 ONLY – Additional 10 points

Calculate the current–voltage (I_{DS} – V_{DS}) characteristics for $0 < V_{DS} < 2\text{V}$ for the Si quantum wire FET when $V_G = 0\text{V}$ and sketch them. Ignore the quantum capacitance, but assume that $C_G = C_S = C_D$.

Question 3. Bilayer atomic sheet (20 points)

Consider the following atomic bilayer sheet. Two layers of simple square 2D sheet were attached to each other. Assume that the spacing between all atoms is a_0 .

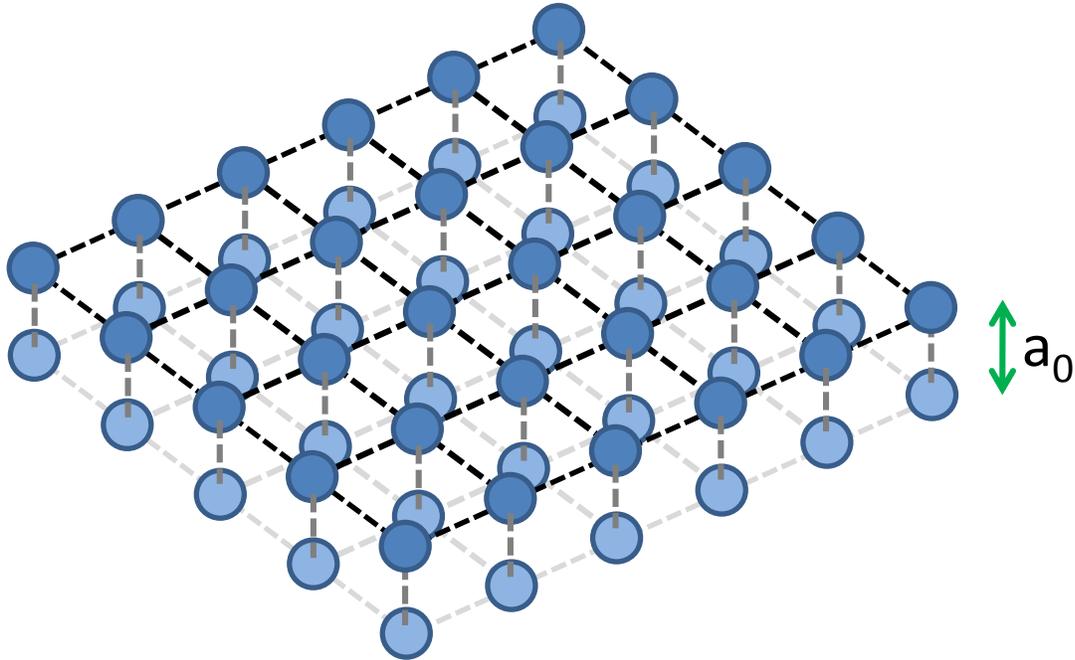


Figure 1 Bilayer Atomic Sheet

a) Calculate the band structure of this bilayer atomic sheet. Assume α is the self energy and β is the hopping interaction. Ignore all other interactions.

b) Is this material metallic or insulating? Assume that each atom donates one electron from the frontier orbital.

Question 4. Seesaw logic (20 points)

Consider a new type of logic circuit based on the seesaw. Each seesaw is stable in two positions. Assume that no energy is dissipated in changing the state of the seesaw.

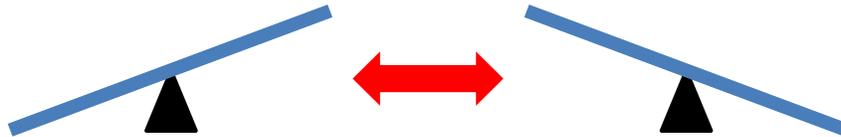


Fig. 1. The two states of a seesaw.

To make a logic element, adjacent seesaws are connected by springs. The springs stabilize seesaws in a saw tooth pattern.

Fig. 2. Two seesaws connected by a spring.

Because there are two possible saw tooth patterns, bits can be represented by pairs of seesaws.

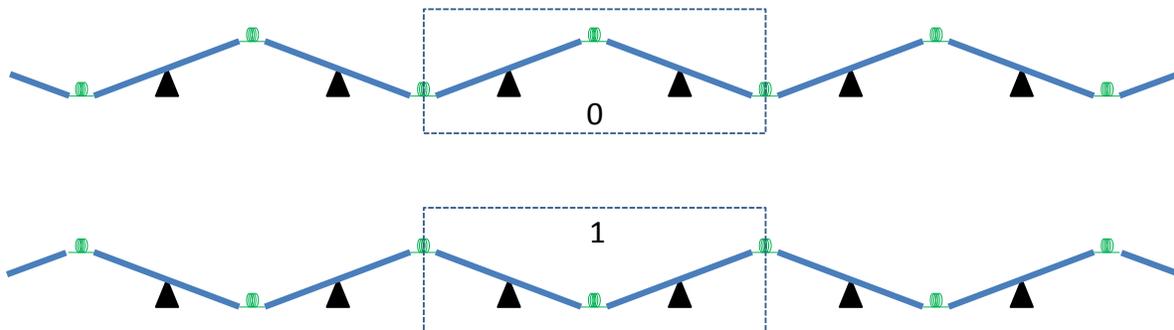


Fig. 3. Saw tooth patterns of spring-connected seesaws. Any adjacent pair of seesaws can be in either the '0' configuration, or the '1' configuration.

(a) Design a majority voting gate with three inputs and one output. The output should be '1' if two or more of the inputs are '1'.

(b) Design a NAND gate with two inputs, i.e. the output should be '0' only if both inputs are '1'.

(c) Calculate the energy dissipation in the NAND gate.

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