EEL4937.002/6936.001 Introduction to Nanotechnology Fall 2002

EXAM I Thursday, Oct,17th 2002

Graduate Student: YES/NO

NAME: SOLUTIONS SS#: _____

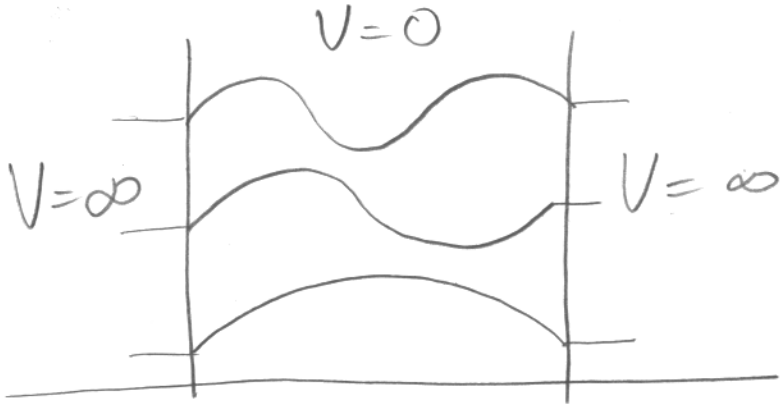
GENERAL RULES:

This is a CLOSED PAPERS, BOOKS and NOTES test.
You are allowed to use a handwritten 8 1/2 x 11" SHEET (both sides)
You must turn in your sheet with the test (Please, write your name on it)
TOTAL POINTS: 100

GOOD LUCK !!!!!!

Question #1 (10pts):

Draw an infinite potential well and the wave functions of the **first three** electronic states (5pts).



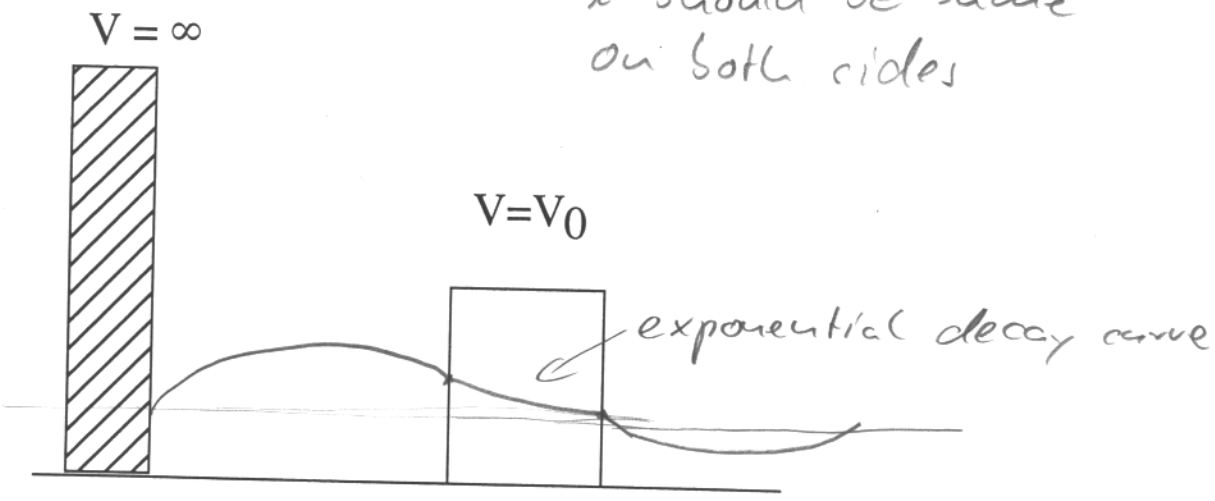

Why do only discrete electronic states exist in the infinite potential well? Write only one sentence. If you write more than one, indicate which one we are supposed to grade (5 pts).

Since the electrons are confined

Question #2 (15pts):

Tunneling through a potential barrier. Draw a possible wave function for a particle that is initially inside the well into the infinite potential barrier/finite tunneling barrier system below. Make sure the wave function fulfills the boundary condition of continuity across its entire expansion. Keep in mind that the energy of the particle remains the same as it tunnels through the barrier (10pts).

↳ E should be same on both sides



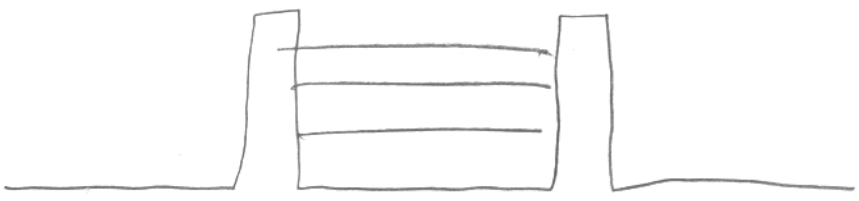

What is the meaning of a particle's wave function with regard to the location of this particle? Write only two sentences. If you write more than two, indicate which ones we are supposed to grade (5pts).

Square of absolute value of wave function represents probability to find ~~electron~~ particle at certain position x

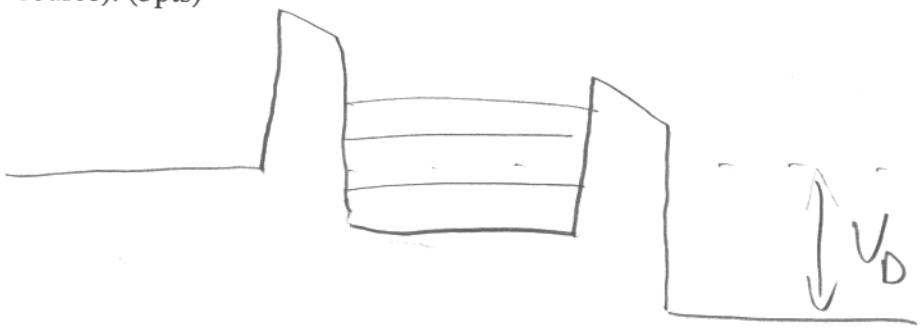
$P(x) = |\Psi(x)|^2$

Question #3 (15pts):

Draw a single electron transistor schematic (conduction band edge) energy diagram at zero applied source-drain voltage including discrete energy states (5pts).



Draw a single electron transistor schematic with a positive drain voltage (relative to source). (5pts)




Draw a schematic I-V diagram of the source-drain current as the source-drain voltage is varied. Assume three discrete energy states in the well (5pts).

Question #4 (13pts):

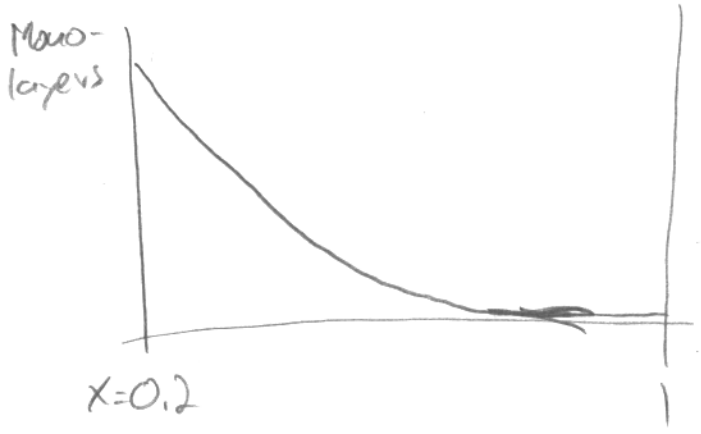
Molecular beam epitaxy of quantum dots (Petroff paper)

Would it be possible to grow Si quantum dots on Si (2pts)? YES (NO) (no strain...)

Why do quantum dots occur if $In_xGa_{(1-x)}As$ (x>0.2) is grown on GaAs? Write only two sentences. If you write more than two, indicate which ones we are supposed to grade (3pts).

Strain between the layers (due to different lattice parameters) causes island growth.

Draw a schematic graph showing the relation between the stoichiometric parameter x and the number of $In_xGa_{(1-x)}As$ monolayers that need to be grown on the GaAs substrate before dot growth occurs (5pts).




Why does the number of $In_xGa_{(1-x)}As$ monolayers vary with x? Write only one sentence. If you write more than one, indicate which one we are supposed to grade (3pts).

Gradual increase of x causes gradual increase of strain between layers.

Question #5 (10pts):

Zhuang paper about single-electron quantum dot transistor switch:

What was the process used to **pattern** the channel between source and drain (2pts)?

electron beam lithography

What was the **wafer type** used enabling the preparation of the 16 nm diameter channel (2pts)?

SOI (Si on insulator) wafer

How did the "quantum dots"-like electron confinement come about in the channel? Write only one sentence. If you write more than one, indicate which one we are supposed to grade (3pts).

dot-like structures developed due to the imperfections of the electron beam litho process.

Why do the peaks in the drain current vs. gate voltage become more pronounced at lower temperatures? Write only two sentences. If you write more than two, indicate which ones we are supposed to grade (3pts).

Since larger dots have more closely spaced discrete energy levels, it needs lower temperatures to reveal these states in the I-V curve. At higher temperatures I-fluktuations due to thermal noise obscure these peaks.

Question #6 (17pts):

Electron Microscopy:

Which three basic types of electron microscopes are used (listing the three acronyms is enough)? (3pts)

SEM, TEM, STEM

Calculate the (non-relativistic) wavelength of a 300keV electron. $\lambda=h/p$; $p=mv$; $E=1/2mv^2$. h=6.62e-34Js. e=1.602e-19 C (5pts). $m = 0.9 \cdot 10^{-30}$ kg

$$\lambda = \frac{h}{\sqrt{2meU}} = 0.00223\,nm$$

How does this wavelength compare to the typical atom diameter (only one short statement)? (2pts)

atom $\cong$ 0.3 – 0.4 nm

$\lambda$ is 2 magnitudes smaller

State the two reasons why samples are placed very close to the lens in a microscope? Write only two sentences. If you write more than two, indicate which ones we are supposed to grade (5pts).

1) To get maximum magnification

2) To "catch" as many diffraction orders with the lens as possible

What is the main limiting resolution factor in a TEM? Write only one sentence. If you write more than one, indicate which one we are supposed to grade. (2pts)

The poor quality of the electron lenses in the objective and magnifying stages.

Question #7 (13pts):

Micro-bull paper:

Why is a two-photon process needed to make this process work? Write only two sentences. If you write more than two, indicate which ones we are supposed to grade. (5pts) Two-photon processes occur only in high-intensity areas. This allows to avoid polymerization where the beams penetrate through the specimen to reach the crossing point where the voxel is written.

Why is the resolution of the process much better than the wavelength of the laser light used? Write only one sentence. If you write more than one, indicate which one we are supposed to grade (3pts).

The requirement for high light intensity concentrates the process in the top part of the beam profile which is narrower than the peak width.

What is its approximate resolution (state number plus proper units)? (2pts)

~120nm

Why does the voxel size depend on the laser exposure time? Write only two sentences. If you write more than two, indicate which ones we are supposed to grade. (3pts)

Longer exposure time elevates the low intensity areas of the beam above the polymerization threshold, increasing the voxel size.

Question #8 (7pts):

Scanning Tunneling Microscopy:

What quantity is used as feedback for the tip-sample distance determination (state proper expression)? (2pts)

tunneling current

How close is a STM tip to the sample surface (give an approximate number and proper units)? (2pts)

$\sim 4-5\ \text{Å}$

Which are the two main parameters determining the magnitude of the tunneling current (at constant tunneling voltage). State proper expressions. (2pts)

1) Density of states in tip and sample

2) Tip-Sample distance

Can a STM be used on insulating samples (1pts)? YES (NO)

( current needs to be passed through sample... )