Quantum (Dot & Wire) & Single Electron transistor (SET)

ELEC 4704 A

Lab 5

Author:

Harshpreet Kaur Kathuria

Student ID: 101102114

Table of Contents

1.0 INTRODUCTION

This lab focuses on multiple concepts of quantum mechanics, the first one being discussed in section 2.0 is the atomic spectrum observed in single electron atoms. This lab focuses on the hydrogen atom and the single ionized Helium atom. Section 2 discussed the generalized for of the wavelength formulae for the hydrogen atom and ionized Helium atom on electron transition from one energy level to another, along with the energy level formula for ionized helium atom. Lastly section2, uses MATLAB to find what energy level transition provide wavelength in visible region in ionized Helium atom. Section 3 discusses the heterojunction behavior between $Al_xGa_{1-x}As/GaAs$ the band gap values are analyzed for provided specifications along with band bending behavior with formation of 2DEG. Next, section 4 dives deeper into application of heterojunctions with analysis if a InAS | GaAs | InAs | GaAs | InAs resonant Tunnel Diode. Finally, the lab results are discussed in the conclusion.

2.0 DENSITY OF STATE: QUANTUM WIRE

This section simulated the behavior of a quantum wire in various specifications using MATLAB.

2.1 This part calculates and plots the density of state vs electron energy of a quantum wire for a system upto: $n_x^2 + n_y^2 = 16$

The MATLAB code for this section is provided below:

```
hbar = 1.05457*(10^(-34));
hbar_sq = hbar*hbar;
pi_sq = pi*pi;
m = 9.1*(10^(-31));
Lx = 2*(10^(-9));
Ly = 2*(10^(-9));

n1 = [1, 2];
n2 = [1, 2, 3];

x = 1;
z = 1;
while (x < 3)
    y = x;
    while (y < 4)
        Emin(z) =
((hbar_sq*pi_sq)/(2*m))*(((n1(x)*n1(x))/(Lx*Lx))+((n2(y)*n2(y))/(Ly*Ly)));
        Emin(z) = Emin(z) + (hbar_sq/(8*m));
        y = y + 1;
        z = z + 1;
    end
    x = x + 1;
end
```

```
E1 = linspace(Emin(1), 3*Emin(1), 10000);
E2 = linspace(Emin(2), 3*Emin(2), 10000);
E3 = linspace(Emin(3), 3*Emin(3), 10000);
E4 = linspace(Emin(4), 3*Emin(4), 10000);
E5 = linspace(Emin(5), 3*Emin(5), 10000);

 g1 = (1/(hbar*pi)).*sqrt((2*m)./(E1-Emin(1)));
 g2 = (1/(hbar*pi)).*sqrt((2*m)./(E2-Emin(2)));
 g3  = (1/(hbar*pi)).*sqrt((2*m)./(E3-Emin(3)));
 g4  = (1/(hbar*pi)).*sqrt((2*m)./(E4-Emin(4)));
 g5  = (1/(hbar*pi)).*sqrt((2*m)./(E5-Emin(5)));

 plot(E1,g1)
 hold on
 plot(E2,g2)
 hold on
 plot(E3,g3)
 hold on
 plot(E4,g4)
 hold on
 plot(E5,g5)
 hold on
```

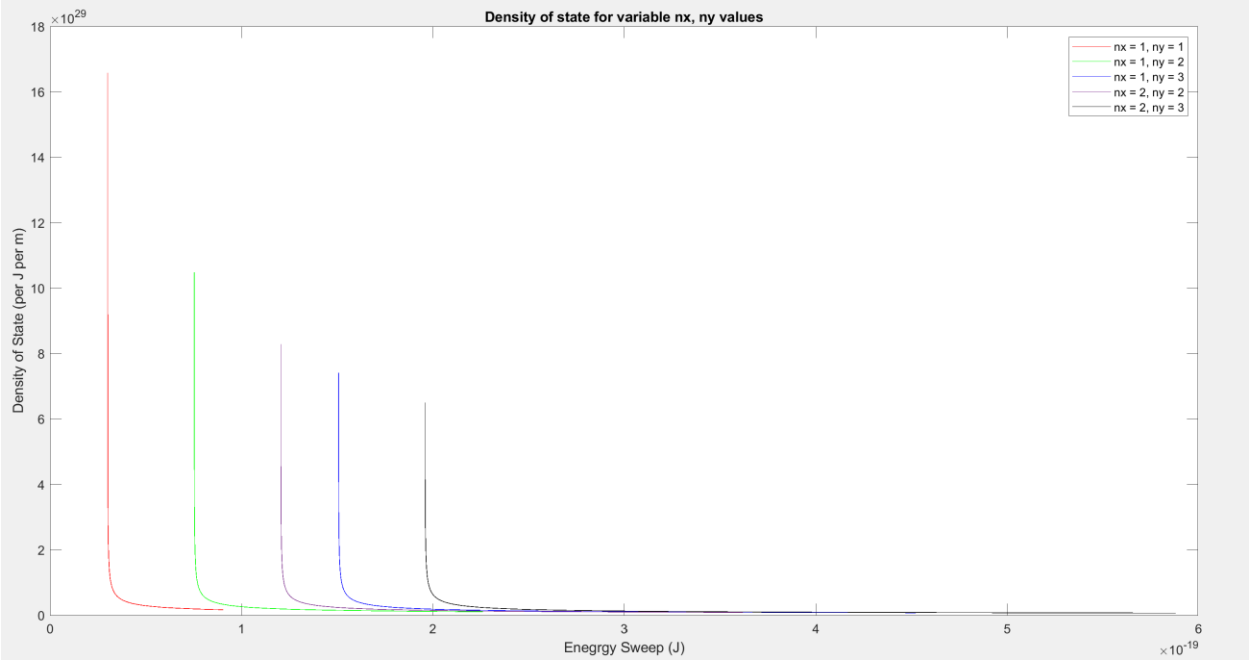

Figure 1: Density of State for a Quantum Wire with variable nx, ny

2.2 On a single graph plot DOS curves with Ly increasing to 4nm, 8nm, 16nm (holding Lx = 2.0nm) and include the bulk (3D) DOS for comparison

The MATLAB code for this section is provided below, the bulk was not plotted as it resulted in improper visualization of the rest of the graph. *See appendix for the bilk plot

```
      %Assume nx = ny =1;


hbar = 1.05457*(10^(-34));

hbar_sq = hbar*hbar;
pi_sq = pi*pi;
m = 9.1*(10^(-31));
Lx = 2*(10^(-9));
Ly = [2, 4, 8, 16]*(10^(-9));
nx = 1;
ny = 1;

x = 1;
while (x < 5)
    Emin(x) =
((hbar_sq*pi_sq)/(2*m))*(((nx*nx)/(Lx*Lx))+((ny*ny)/(Ly(x)*Ly(x))));
    Emin(x) = Emin(x) + (hbar_sq/(8*m));
    x = x + 1;
end
E1 = linspace(Emin(1), 3*Emin(1), 10000);
E2 = linspace(Emin(2), 3*Emin(2), 10000);
E3 = linspace(Emin(3), 3*Emin(3), 10000);
E4 = linspace(Emin(4), 3*Emin(4), 10000);

 g1 = (1/(hbar*pi)).*sqrt((2*m)./(E1-Emin(1)));
 g2 = (1/(hbar*pi)).*sqrt((2*m)./(E2-Emin(2)));
 g3  = (1/(hbar*pi)).*sqrt((2*m)./(E3-Emin(3)));
 g4  = (1/(hbar*pi)).*sqrt((2*m)./(E4-Emin(4)));

%BULk
 E =  (hbar_sq)./(8*m);
 Espace = linspace(0, 1.1*E, 10000);
 g_bulk= (1/(hbar*pi)).*sqrt((2*m)./(Espace));

%  plot(Espace, g_bulk, 'r')
%  hold on
 plot(E1,g1,'b')
 hold on
 plot(E2,g2, 'g')
 hold on
 plot(E3,g3 ,'r')
 hold on
 plot(E4,g4,'k')
 hold on
 title('Density of state for variable Ly values with Lx = 2nm')
 ylabel('Density of State (per J per m)')
 xlabel('Enegrgy Sweep (J)')
 legend({'Ly = 2nm', 'Ly = 4nm', 'Ly = 8nm','Ly = 16nm'})
```

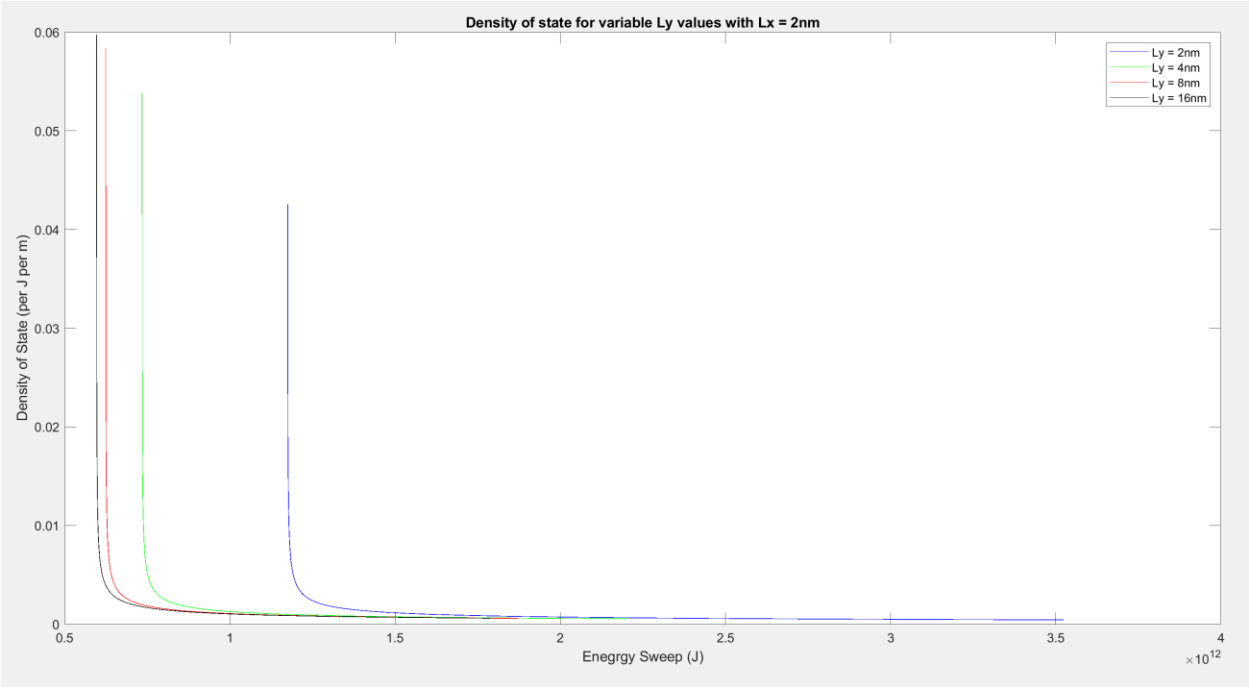

Figure 2: Density of State for a Quantum Wire with variable Ly

2.3 Find a general expression for emission wavelengths for He+ between two levels

The MATLAB code for this section is provided below, the bulk was not plotted as it resulted in improper visualization of the rest of the graph. *See appendix for the bilk plot

```
%Assume nx = ny =1;


hbar = 1.05457*(10^(-34));
hbar_sq = hbar*hbar;
pi_sq = pi*pi;
m = 9.1*(10^(-31));
Ly = 16*(10^(-9));
Lx = [2, 4, 8, 16]*(10^(-9));
nx = 1;
ny = 1;

x = 1;
while (x < 5)
    Emin(x) =
((hbar_sq*pi_sq)/(2*m))*(((nx*nx)/(Ly*Ly))+((ny*ny)/(Lx(x)*Lx(x))));
    Emin(x) = Emin(x) + (hbar_sq/(8*m));
    x = x + 1;
end
E1 = linspace(Emin(1), 3*Emin(1), 10000);
E2 = linspace(Emin(2), 3*Emin(2), 10000);
E3 = linspace(Emin(3), 3*Emin(3), 10000);
E4 = linspace(Emin(4), 3*Emin(4), 10000);
```

```
g1 = (1/(pi*hbar)).*sqrt((2*m)./(E1-Emin(1)));
g2 = (1/(pi*hbar)).*sqrt((2*m)./(E2-Emin(2)));
g3  = (1/(hbar*pi)).*sqrt((2*m)./(E3-Emin(3)));
g4  = (1/(hbar*pi)).*sqrt((2*m)./(E4-Emin(4)));



E =  (hbar_sq)./(8*m);
Espace = linspace(0, E, 10000);
%ESpace = sqrt(Espace);
g_bulk= (1/(hbar*pi)).*sqrt((2*m)./(Espace));

%  plot(Espace,g_bulk,'p')
%  hold on
plot(E1,g1, 'b')
hold on
plot(E2,g2,'k')
hold on
plot(E3,g3, 'g')
hold on
plot(E4,g4, 'r')
hold on
title('Density of state for variable Ly values with Ly = 16nm')
ylabel('Density of State (per J per m)')
xlabel('Enegrgy Sweep (J)')
legend({'Lx = 2nm', 'Lx = 4nm', 'Lx = 8nm','Lx = 16nm'})
```

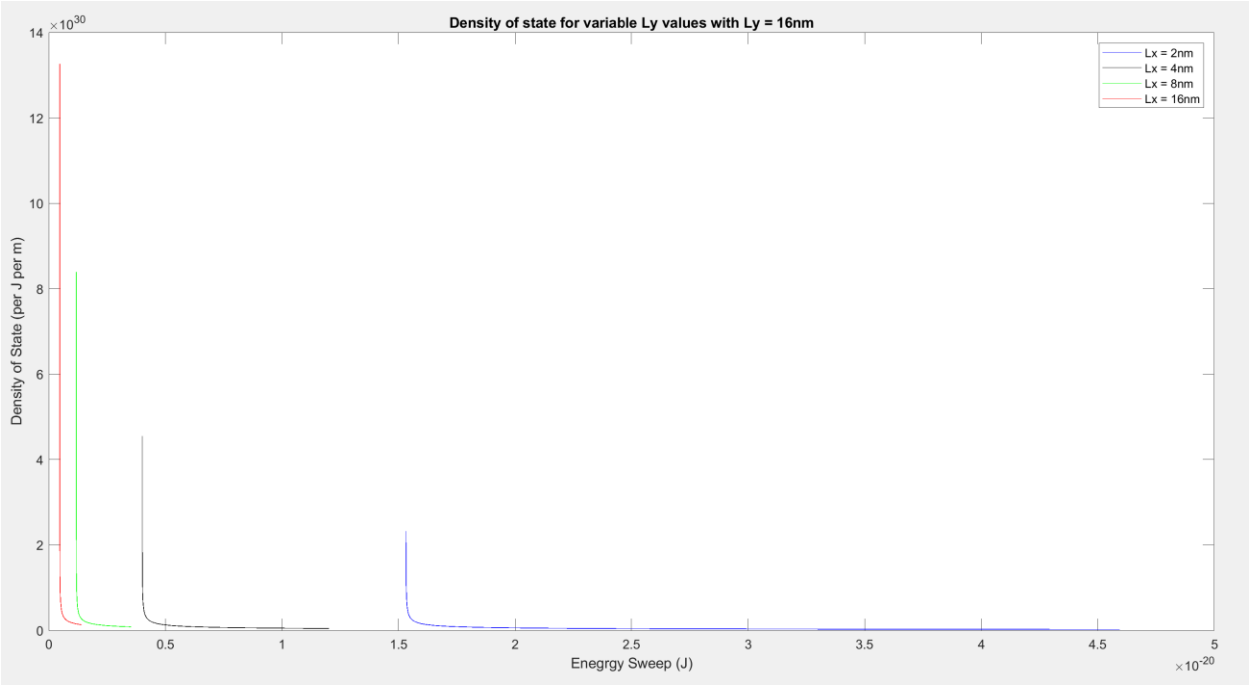

Figure 3: Density of State for a Quantum Wire with variable Lx

3.0 QUANTUM DOT & OPTICAL TAGGING

This section focuses on properties of a quantum dot built using CdTe centered its using at 510nm.

3.1 Using the data from the Nanocrystal Quantum Dot slideset, calculate the appropriate target radius, a, for a spherical nanoparticle made from CdTe. Along with the radius range for a wavelength uncertainty of 5nm. If the ionization energy to expel electrons into the surrounding matrix is 3.0eV are these quantum dots susceptible to biexciton-Auger

The following MATLAB code is used to calculate the radius of the CdTe nanoparticle, the code given the radius value for the particle to be $5*10^{-20}$ m and for an uncertainty of 5nm, the allowed radius range would be (0.12582, 1.2459) nm. The energy calculated for the designed quantum dot is 2.436eV, hence it is not susceptible to biexciton-Auger expulsion of electrons.

```
wavelength = 510*(10^(-9));
m = 9.1*(10^(-31));
h = 6.626*(10^(-34));
hbar = 1.05457*(10^(-34));
hbar_sq = hbar*hbar;
c = 3*(10^8);
q = 1.6*(10^(-19));

wavelength_minus = wavelength-(5*(10^-9));
wavelength_plus = wavelength+(5*(10^-9));

E = (h*c)/wavelength;
Eplus = (h*c)/wavelength_plus;
E_minus = (h*c)/wavelength_minus;

E = E/q;
a = sqrt(hbar_sq/(2*m*E));
a_plus = sqrt(hbar_sq/(2*m*Eplus));
a_minus = sqrt(hbar_sq/(2*m*E_minus));
```

4.0 SINGLE ELECTRON TRANSISTOR (SET)

This section focuses on analyzing the characteristics of a Ti-TiO_x-Ti-TiO_x-Ti SET structure. Using the geometry information given in the courses slides and the SET article. The capacitance for C1 = C2 = Cg is calculated to be $1.0625*10^{-18}$ F and total capacitance is calculated as sum of all these three which is equal to $3.1875*10^{-18}$ F. The gate voltage (Vg) was calculated to be 0.0753. The minimum acceptable value of voltage across the drain in 0.2259V

The MATLAB code for this problem is given below:

```
epsilonr = 24;
```

```
epsilonfree = 8.8541878*(10^(-12));
epsilon = epsilonfree*epsilonr;
area = (2.5*40)*(10^(-18));
d = 20*(10^(-9));
q = 1.6*(10^(-19));
C = (epsilon*area)/d;
Ctotal = 3*C;
Vg = q/(2*C);
Va =3*Vg;
```

5.0 CONCLUSION

This lab focused on analyzing the Quantum dot and quantum wire behavior along with a single electron transistor. These are some of the basic nanodevices that form the footstep of future quantum technology. A quantum wire in a device such that the electron has freedom of mobility in 1 dimension. For quantum wire it was observed that with increase in the value of n, the allow maximum density of energy keeps decreasing and so does the minimum allowed energy. The opposite trend was found for the values of Ly and Lx, this trend makes complete sense as the density of energy is directly proportional to n^2 and inversely proportional to L^2.

For the radius of the quantum dot was calculated along with the allowed energy for the stability of a quantum dot. For the single electron transistor, the capacitance of the system, gate voltage and drain potential were calculated for a Ti-TiO_x-Ti-TiO_x-Ti SET of given dimensions the total capacitance calculated was $3.1875*10^{-18}$ F, the calculated gate potential was 0.0753V and the drain potential was 0.2259V.

This lab was were profound to understand the concepts covered in the course better.

APPENDIX

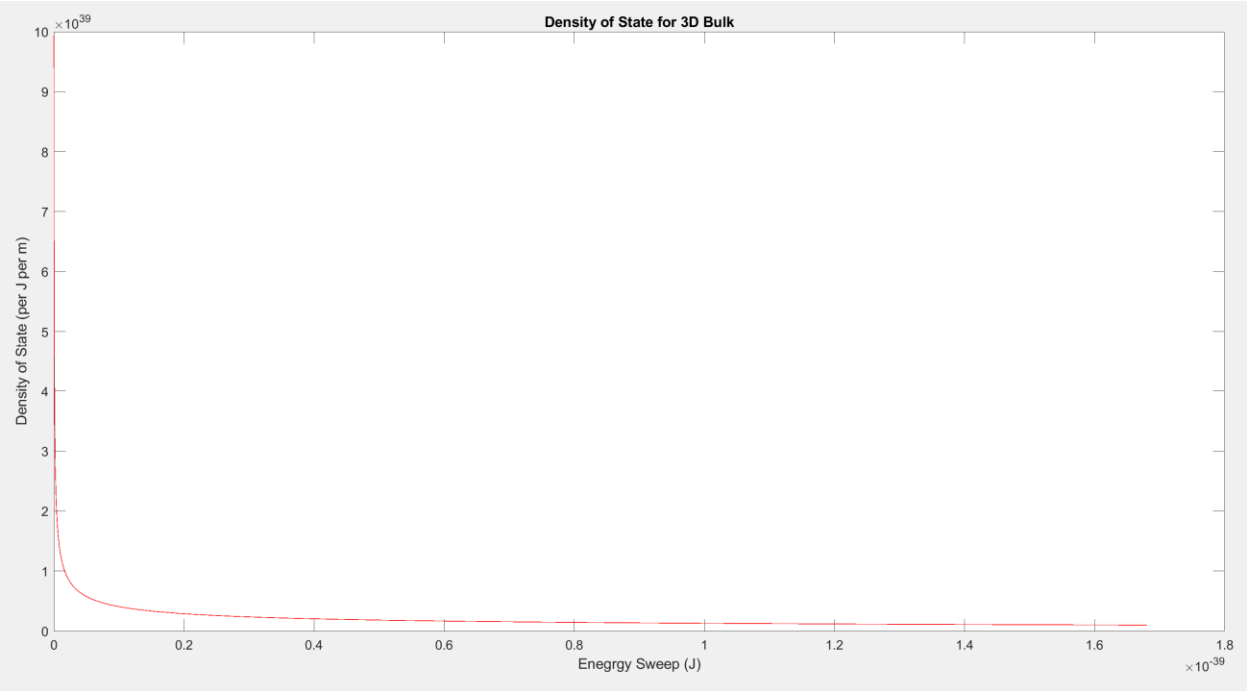

Figure 4: Density of State Vs Energy plotted for a Bulk 3D state