**Atomic Spectra for Single Electron Atoms**

**&**

**Semiconductor Alloy Behavioral Analysis**

ELEC 4704 A

Lab 4

Author:

Harshpreet Kaur Kathuria

Student ID: 101102114

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# **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 AlxGa1-xAs/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 ATOMIC SPECTRUM**

**2.1 Using the formulae for the major energy levels of a hydrogen atom, En , find a general expression for the emission wavelengths between two levels.**

**2.2 Singly ionized helium atoms, He+ , are very similar to the hydrogen atom except that the nucleus now has a charge of +2q. Assuming that this change to the Coulomb potential is the only difference, find a general expression for the major energy levels, En , for He+ .**

The energy levels for single electron atoms are treated equally. Hence the energy only difference in the formulae for energy level would be due to 2q charge of the nucleus.

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

**2.4 Between which energy levels will the emission for He+ be visible? What visible wavelengths will be emitted? (Light is visible between about 400nm and 700nm.)**

Matlab was used to solve the above question. The results obtained are displayed below:

A picture containing text

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MATLAB code that generated these results is:

%Between which energy levels will the emission for He+ be visible?

% What visible wavelengths will be emitted?

% (Light is visible between about 400nm and 700nm.)

n2 = 10;

while (n2 > 1)

n1 = 1;

Wavelength = linspace(1,n2-1,n2-1);

while (n1 < n2)

inverse\_lambda = 4.388\*(10^7)\*((1/(n1\*n1))-(1/(n2\*n2)));

lambda = (1/inverse\_lambda)\*(10^9);

Wavelength (n1) = lambda;

if ((400 < lambda) && (lambda<700))

fprintf('Transition from %d to %d emits wavelength in visible range %f nm \n', n2, n1, lambda);

end

n1 = n1 + 1;

end

Wavelength;

n2 = n2 -1;

end

# **3.0 HETROJUNCTION**

The conduction band-offset for an AlxGa1-xAs/GaAs heterojunction is 60% of the difference of the bandgaps of these materials.

**3.1 Find the composition of the AlxGa1-xAs layer necessary for the resulting heterojunction to have an energy barrier for the electrons equal to 0.3eV**

x = 0.24

**3.2 Calculate the energy barrier for the holes.**

Since we know that the conduction band is 60% of the difference of the bandgap this mean that the energy barrier for the holes is 60% of the energy barrier.

**3.3 Sketch the band diagram for the system assuming the AlxGa1-xAs layer is heavily n-doped and the GaAs layer is lightly p-doped. (Showing the band-bending due to charge transfer.) Indicate if/where a 2DEG might be formed in the structure.**

Diagram

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Figure 2: Band Diagram for AlxGa1-xAs/GaAs Heterojunction depicting Band Bending [1]

**Diagram

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Figure 3: 2DEG being depicted for AlxGa1-xAs/GaAs Heterojunction depicting Band Bending [2]

Figure 1 depicts a generalized perspective on the band bending of a type 1hetro junction. In figure 2 it can be observed if the fermi level is too high such that it is more than the minimum level of conduction band due to bending, it results in 2DEG.

# **4.0 RESONANT TUNNEL DIODE (RTD)**

* 1. **Plot the transmission, T, versus energy, E, for this device up to E=V0. Assume all of the bandgap difference between the InAs and GaAs appears in the conduction band, and you can use an average effective mass, m\*. (See the slides from Lecture 5 for the material parameters required.**

The solution for this part could not be successfully plotted as the cosh and sinh value in the function kept approaching infinity.

The MATLAB code used can be found bellow:

% Plot the transmission, T, versus energy, E, for this device up to E=V0.

% Assume all of the bandgap difference between the InAs and GaAs appears in

% the conduction band and you can use an average effective mass, m\*.

% (See the slides from Lecture 5 for the material parameters required.)

q = 1.6\*(10^(-19));

m = 0.046\*q;

V = q;

e = 2.718;

hbar = 6.5821\*(10^(-16))\*q;

Lb = 4\*(10^(-9));

Lw = 10^(-8);

E = linspace(0,V, 524288);

beta = (sqrt(2.\*m.\*(V-E)))/hbar;

k = sqrt(2.\*m.\*E)/hbar;

a = Lb.\*beta;

b = ((e.^a) + (e.^(-1\*a)))./2;

c = ((e.^a) - (e.^(-1\*a)))./2;

K1 = 2.\*(power((E.\*(V-E)),0.5)).\*b.\*(cos(Lw.\*k));

K2 = (E+E-V).\*c.\*sin(Lw.\*k);

K = K1- K2;

A = (V.\*c.\*K)./(2.\*E.\*(V-E));

A\_squared = A.\*A;

T = 1./(1 + A\_squared);

plot(E,T);

* 1. **Find the energies of the “quasi-bound states”, En.**

The above formula is used to calculate the energy levels of the quasi-bound states in MATLAB. The results found are shown below:

**Table

Description automatically generated**

The MATLB code used to calculate the results is given below:

% Find the energies of the "quasi-bound states”, En.

m= 0.046;

hbar = 6.5821\*(10^(-16));

Lw = 10^(-8);

n = 1;

while (n<11)

En = ((pi\*hbar\*hbar\*n\*n)/(2\*m\*Lw\*Lw))\*1000000000000;

fprintf ('The value of %d th Energy is (10^-12)\* %f eV \n', n, En);

n=n+1;

end

* 1. **By fitting the transmission peaks from (a) above to the approximate Lorentzian form discussed in class find the approximate lifetime for electrons in each of the quasi-bound states.**

# **5.0 CONCLUSION**

This lab discussed the behavior of single electron atoms, while focusing on photon emission and the wavelength of light emitted during particular levels of electron transmission. A substantial result found in this case is that the transition to level four results in visible light being transmitted in case of an ionized Helium atom, whereas in case of hydrogen, it is at level two. This makes complete sense as the wavelength is directly proportional to the square of the atomic number. In section three the composition for AlxGa1-xAs/GaAs is found by using energy gap equal to 0.3eV. The value of x found was 0.24. this value aligns with the expectation that the x value expected was supposed to be less than 0.4. Section 4 is analysis of a practical application of heterojunction semiconductors, a resonant tunnel diode is analyzed. The quasi-bound energy states of the structure are calculated using MATLAB.

# **References**

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| [1] | Nanite, "Wikipedia," 9 June 2013. [Online]. Available: https://commons.wikimedia.org/wiki/File:Band\_Alignment\_at\_a\_Type\_I\_Heterojunction.png. [Accessed 24 November 2022]. |
| [2] | M. S. C.-T. G. S. W.R. Clarke, Reference Module in Material Science and Materials Engineering, Elsevier, 2016. |