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Introduction on Carbon Nanotubes (CNT) and Its Applications in Electronic Circuits

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Abstract: Carbon Nanotubes (CNT) in nanotechnology field are legendary for its strength and chemical inertness. Technically, we can alter carbon nanotubes based on our necessities and requirements such as single layered nanotube, double layered nanotube, multi layered nanotube etc. In this paper usage of carbon nanotubes in semiconductor devices such as nanomaterials, molecular dynamics of nanomaterials, heterojunctions using carbon nanotubes, diodes and Graphene Field Effect Transistor (GFET), its characteristics and data analysis are discussed. The major application of carbon nanotubes in electronic circuits is not limiting to improves the electrical and thermal conductivity due to its high stretchability feature and they also have a long life span and better durability over traditional electronic circuit's materials.

Key words: Nanotechnolog; carbon nanotubes; electronic circuit; electronics; nano electronic materials; nano electronics

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Introduction

In electronics, present method used in manufacturing of electronic devices is called "top down" method (i.e. manufacturing nanoscale components and materials from larger chunks) nonetheless researchers are now developing a new approach based on self-assembly of atoms and molecules that is called " bottom up " approach.

Top down method uses the creation of logically smaller structures to be made utilizing utilizes lithography and related methods for the development of electronic components and smaller scale electro mechanical frameworks. This method has encouraged effective data and innovation activities.

Bottom up method is a promising and contradicting option for top down method, one which allows working of nano components rather than litho-graphically cutting into greater bits into smaller and smaller pieces. For example, DNA atoms, might be utilized to control the association of nanoparticles. Another example is carbon nanotubes. This may speed up the capacity to 'develop' parts of a coordinated circuit, as opposed to depending on top down strategies[1,2].

Nanomaterials

Nanomaterials are usually characterized as materials planned and delivered to have auxiliary highlights measuring hundred nanometers or less. In devices, various diverse nanomaterials are utilized monetarily for innovative work. The most common utilizing nanomaterials for electronic and electrical hardware are carbon nanotubes and quantum specks for surface coatings, nanoparticles of silver[1,2].

Nanofabricating

Assembling components at nanoscale is known as Nanofabricating. Nanoabricating includes scaled-up, solid, and savvy assembling of nanoscale materials, structures, devices, and frameworks. It also incorporates research, advancement and various procedures and progressively complex base up or self-gathering forms[1,2].

Carbon Nanotubes in Semiconductor

Carbon nanotubes can be either 'metallic' or semiconductors relying upon the real method in which the carbon iotas (atoms) are gathered in the tube. The metallic structures have electrical conductivities thousand times significant than copper and are presently being blended with polymers to make leading composite materials for applications. For example, electromagnetic protecting in cell phones and friction-based electricity reduction in automobiles. Their utilization has been shown in supercapacitors and nanometer-sized transistors[1,2].

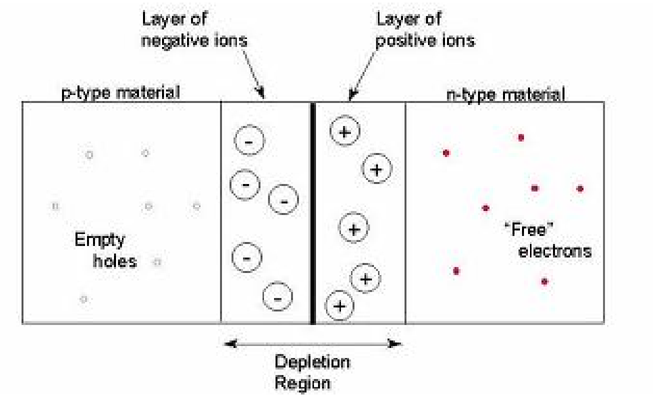

Fig.1 Depicts Conventional Unbiased PN Junction

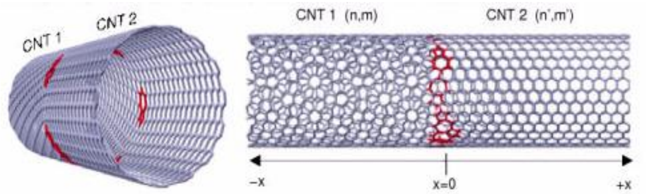

Fig.2 Depicts carbon nanotube heterojunction consists of two Carbon Nanotube (CNT's) of different chirality with similar radii with zero bias[3]

1 Nanomaterials

The structure and geometry of carbon nanotubes create a one of a kind electronic multifaceted nature, halfway because of their size, since quantum material science oversees at the nanometer scale. Yet, graphite itself is an exceptionally uncommon material. While most of the electrical materials such as metals or semiconductors, graphite materials known as a semi-metal. By consolidating graphite's semi-metallic properties with the quantum standards of vitality levels and electron waves, carbon nanotubes rise as exceedingly unusual conveyors. Among various types of nanotubes, single-walled carbon nanotubes (SWCNTs) have the possibility to reforming current electronic components in the industry. In spite of the fact that business in electronic components has effectively gained critical ground in the measurements of transistors. However, it still faces extraordinary hindrances in proceeding with electronic scaling down because of essential physical breaking points. Besides, there are considerable financial motivating forces to shrink these individual devices further, the cost and designing of incorporating carbon nanotubes into ordinary hardware has been restrictive. This test has animated a lot of researches into how to utilize carbon nanotubes in electronic devices, productively and economically. One of the territories of research areas includes the making of vast systems where carbon nanotubes can be adjusted in preset examples, enabling scientists to choose a particular area and chirality for carbon nanotube, and capacity to coordinate the system into an in good condition circuit[4].

A simulation was performed on nanomaterials using Gallium Arsenide (GaAs).

It took about fifteen iterations to attain consistency. Below are the graphs for total energy (Fig.3), density of states (Fig.4), electron occupation statistics (Fig.5) and initial atomic structure (Fig.6).

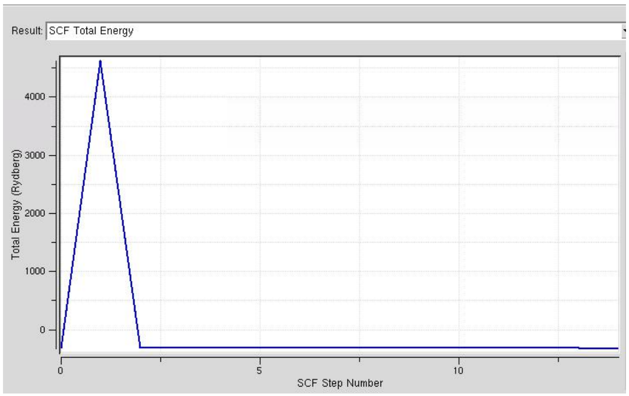

Fig.3 Total Energy[5]

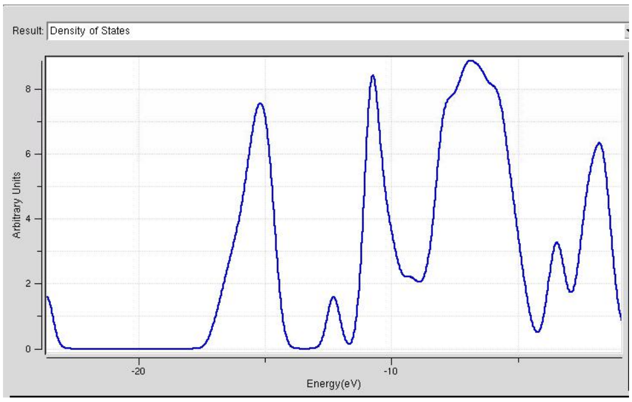

Fig.4 Density of States[5]

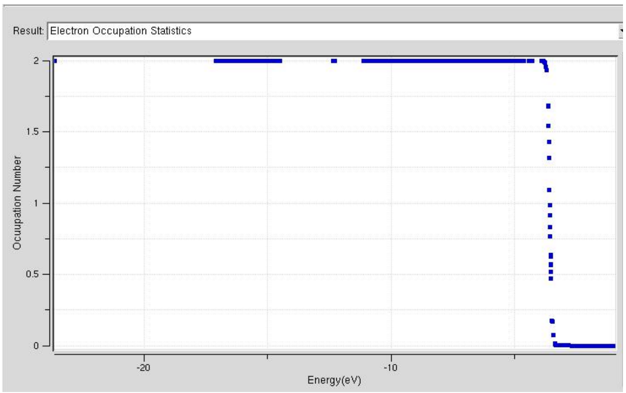

Fig.5 Electron Occupation Statistics[5]

Notes:
Fermi level = -0.262503 Ry, gap (0K) = 0.000490 Ry = 0.007 eV
Delta movement in electrons = 10.0394463841
One-center local charge defect = -0.00000911
Slab dipole removed using vacuum LMCC
Using LMCC treatment of supercell electrostatics
Edge, average potentials= -2.893729660816D-02 1.018629625094D-17
Energy Analysis
Spherical-atom Energy correction = -179.9794104973
Full spherical atom trace Energy = -80.8025506243
Spherical-atom-V_{xc} trace Energy = 91.2925852479
Non-spherical Energy = 0.3333675033
Total E_{xc} Energy = -151.2289074112
Total kinetic trace Energy = 101.7923470920
Non-local ps-pot trace Energy = 53.0750281435

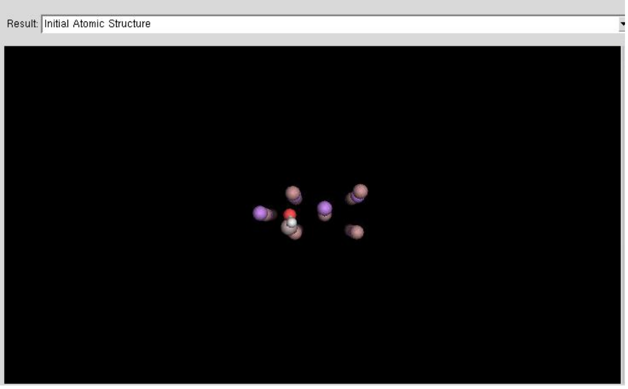

Fig.6 Initial Atomic Structure[5]

Total electrostatic Energy = -324.0233836060
Total V_{xc} Energy = -95.3333983575
Total Energy (Rydberg) = -320.3849157817

2 Molecular Dynamics Nanomaterials

Carbon nanotubes can be exploited as atomic molecular components and sub-atomic wires. Every component depends on a suspended, crossed nanotube geometry that prompts bistable, electrostatically switchable ON/OFF states. Such electronic components can be used to control expansive clusters utilizing carbon nanotube interconnects[6].

A simulation was performed on molecular dynamics of nanomaterial Aluminium (Al) at nano level for a unit cell.

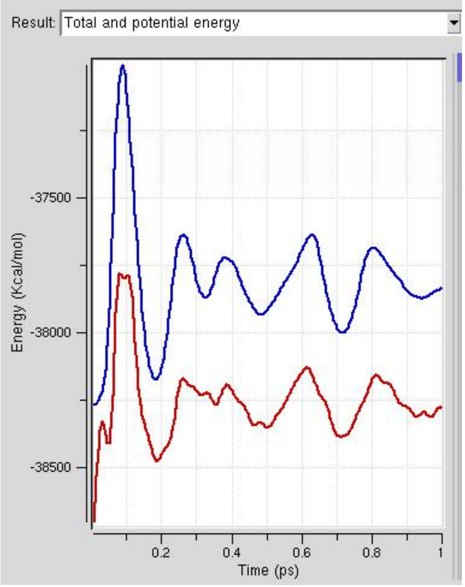

Fig. 7 Total Potential Energy[7]

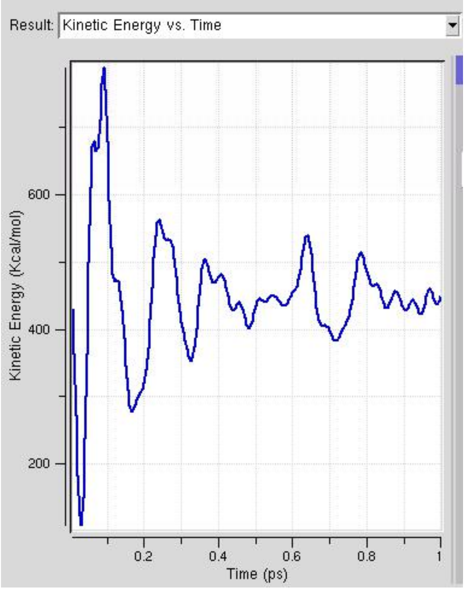

Fig.8 Kinetic Energy vs Time[7]

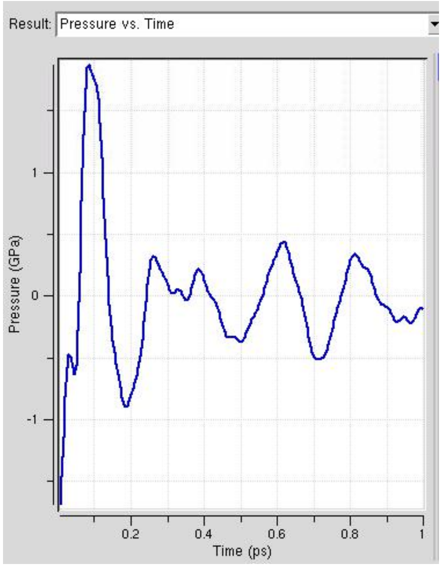

Fig.9 Temperature vs Time[7]

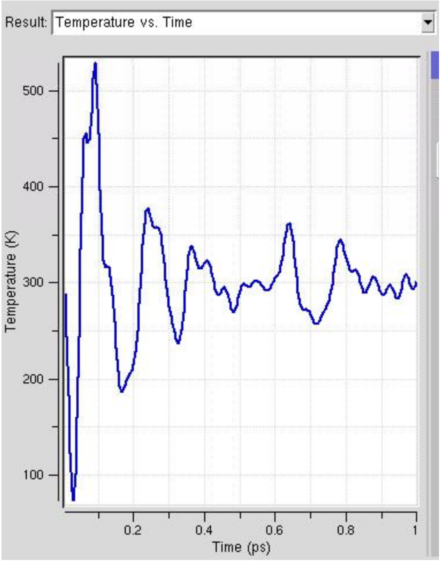

Fig.10 Pressure vs Time[7]

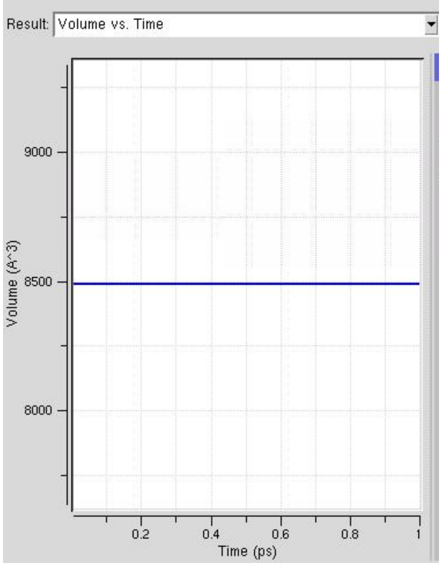

Fig.11 Volume vs Time[7]

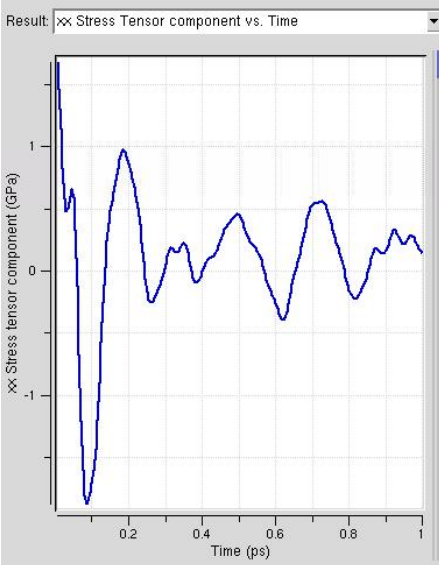

Fig.12 xx Stress Tensor Component vs Time[7]

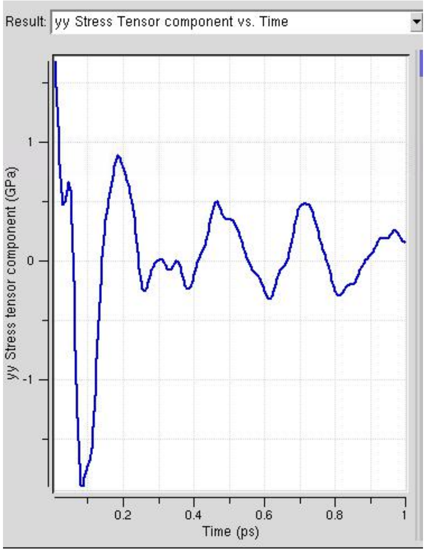

Fig.13 yy Stress Tensor Component vs Time[7]

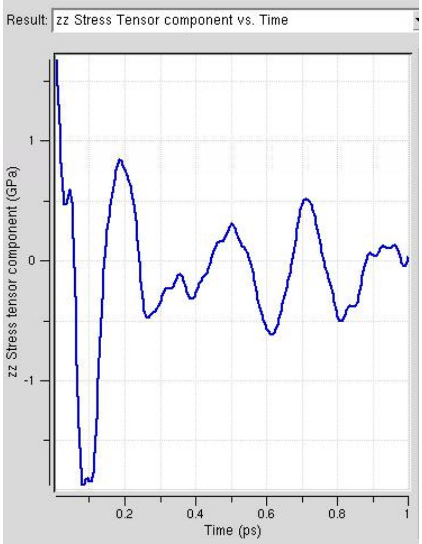

Fig.14 zz Stress Tensor Component vs Time[7]

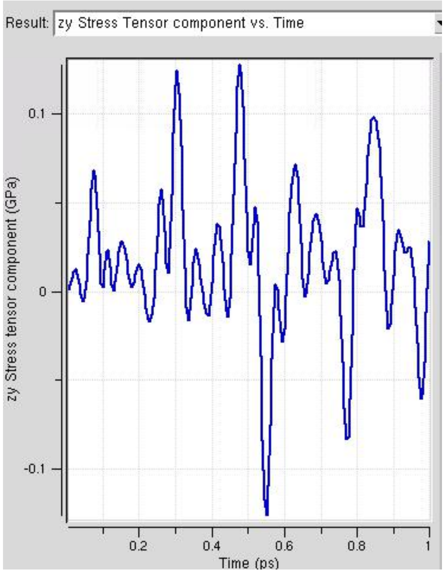
Result: zy Stress Tensor component vs. Time

Fig. 15 zy Stress Tensor Component vs Time[7]

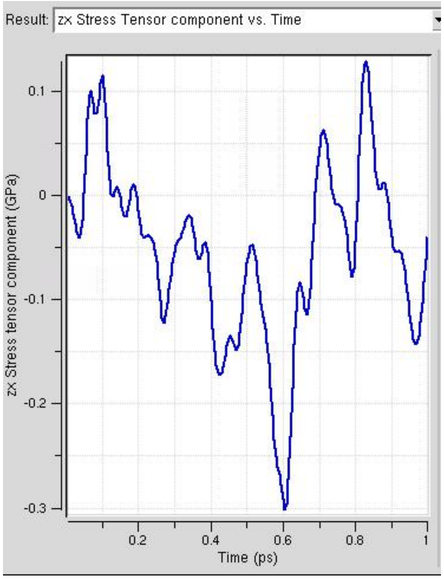
Result: zx Stress Tensor component vs. Time

Fig.16 zx Stress Tensor Component vs Time[7]

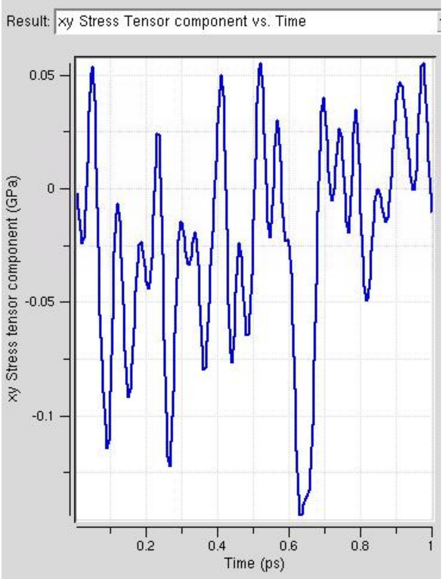
Result: xy Stress Tensor component vs. Time

Fig.17 xy Stress Tensor Component vs Time[7]

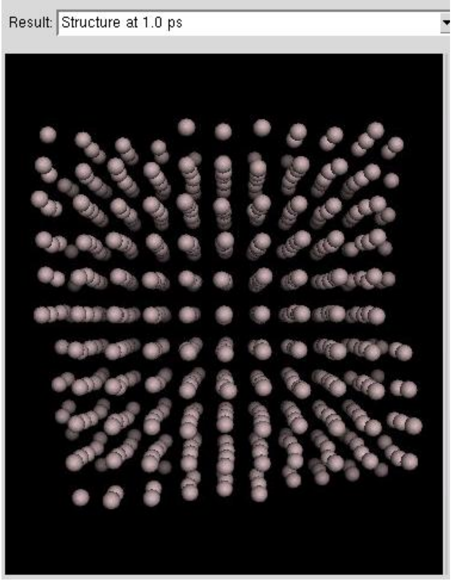
Result: Structure at 1.0 ps

Fig.18 Structure at 1.0 ps[7]

Notes:
Average Values per Atom
Potential Energy: -76.511714675346994
Kinetic Energy: 0.89256330854649224
Total Energy: -75.619151366800509
Temperature: 299.63501404050714
Volume: 16.979327999999857
Pressure: -2.3960296000603138E-002
Stress (GPa) | -0.114429 0.022192 0.053191 |
Stress (GPa) | 0.022192 -0.043341 -0.017250 |
Stress (GPa) | 0.053191 -0.017250 0.085889 |
Spec. heat (k_B) 256.97755507656677

3 Carbon Nanotube (CNT) Heterojunction

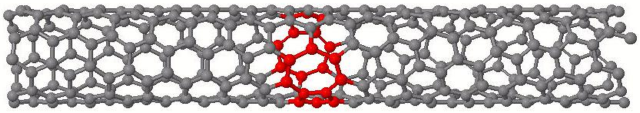

Fig.19 Depicts Heterojunction Structure of a Single Walled Carbon Nanotube[8]

A simulation was performed on Carbon Nanotube Heterojunction (CNT HJ) at nano level. Carbon Nanotube heterojunction consists of two Carbon Nanotubes (CNTs) of different chiralities connected through an interface.

This simulation was used to construct atomistic model of CNT HJs made of two CNTs of different chiralities but similar radii and compute their electronic structure and zero bias transport properties with a nearest neighbor tight binding based Green's function approach.

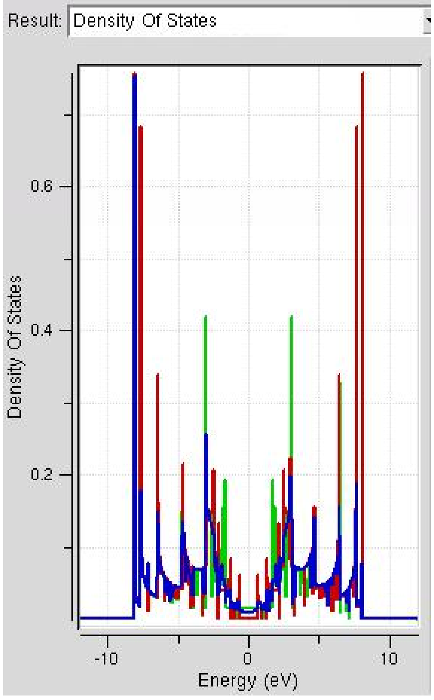

Fig. 20 Density of States[8]

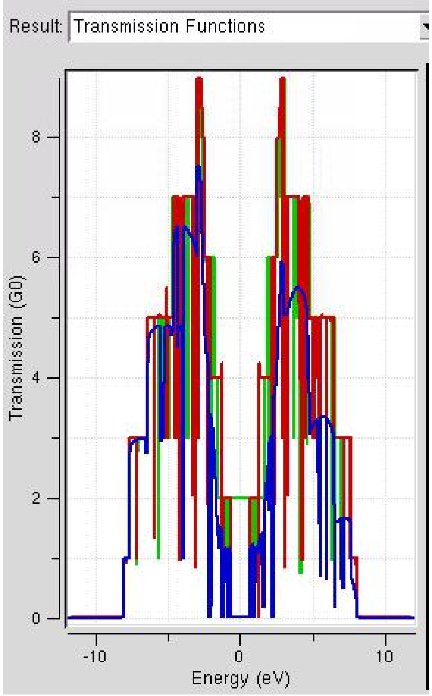

Fig.21 Transmission Functions[8]

Notes:
Tube 1 (5,4)
Length: 20.0 Ang
Radius: 3.06 Ang
Type: Semiconducting
Tube 2 (6,3)
Length: 20.0 Ang
Radius: 3.11 Ang
Type: Metallic
Number of Atoms: 297

4 Diode through Carbon Nanotube

Diodes can be constructed using carbon nanotube using the Gallium Arsenide (GaAs)
A simulation was performed for Diode for the following parameters:
Material: GaAs
Applied Bias: 0.25 V
Lattice Temperature: 300K
Conduction Band: Parabolic

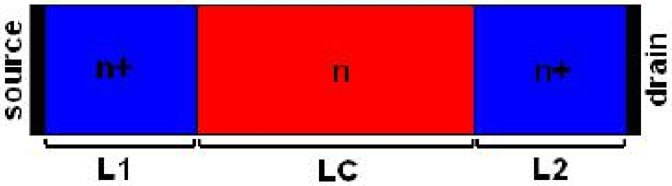

Fig.22 Diode Structure[9]

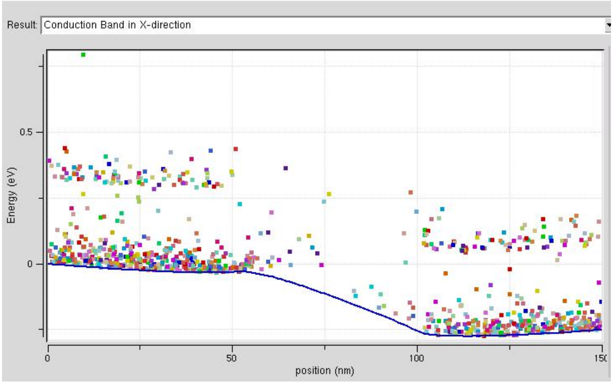

Fig.23 Conduction Band in X-direction[9]

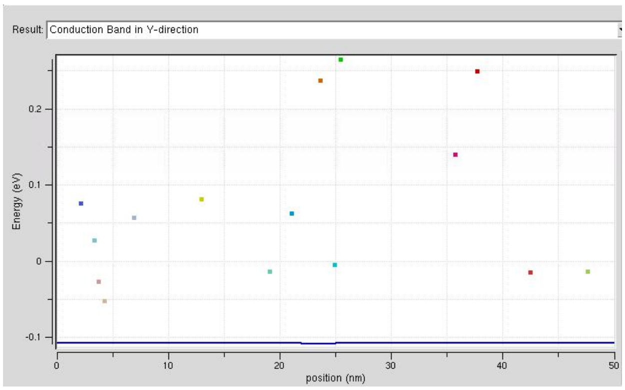

Fig.24 Conduction Band in Y-direction[9]

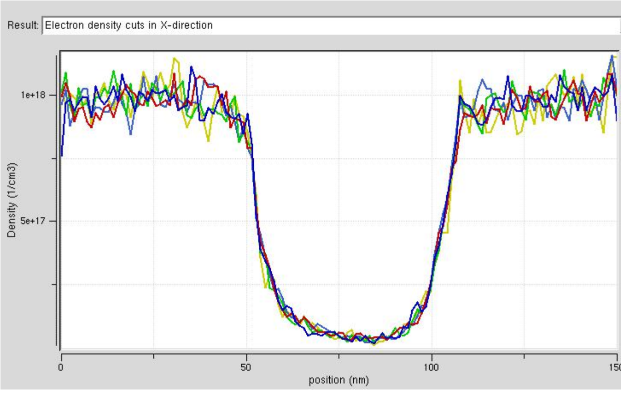

Fig.25 Electron Density Cuts in X-direction[9]

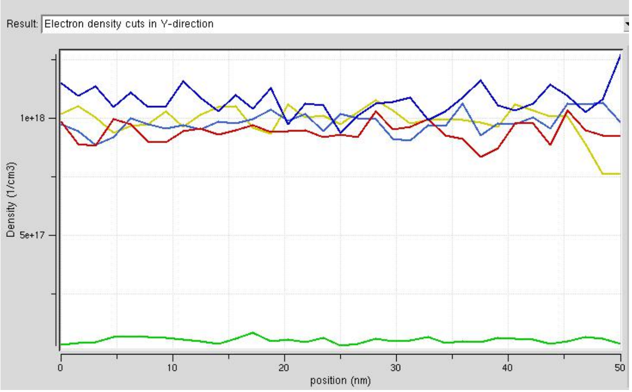

Fig.26 Electron Density Cuts in Y-direction[9]

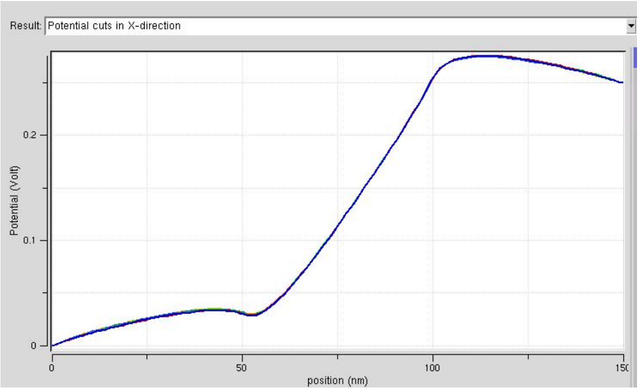

Fig.27 Potential Cuts in X-direction[9]

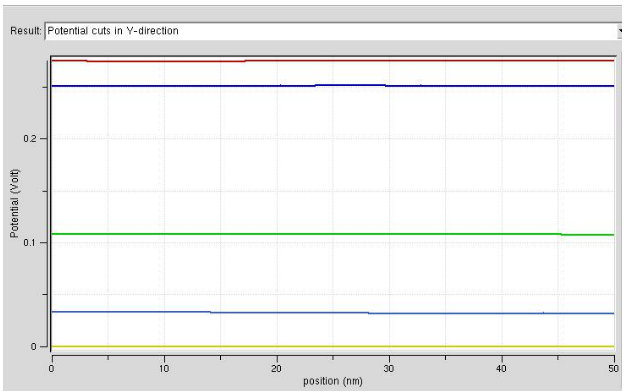

Fig.28 Potential Cuts in Y-direction[9]

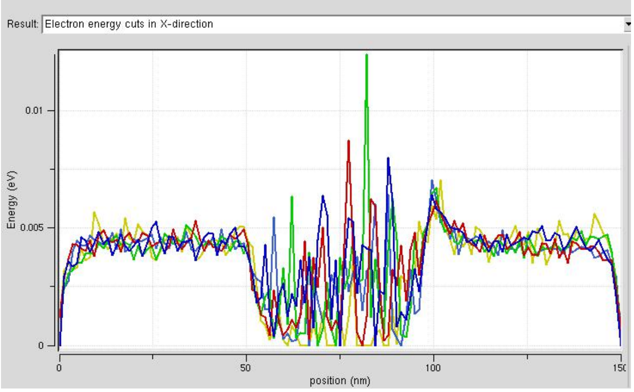

Fig.29 Electron Energy Cuts in X-direction[9]

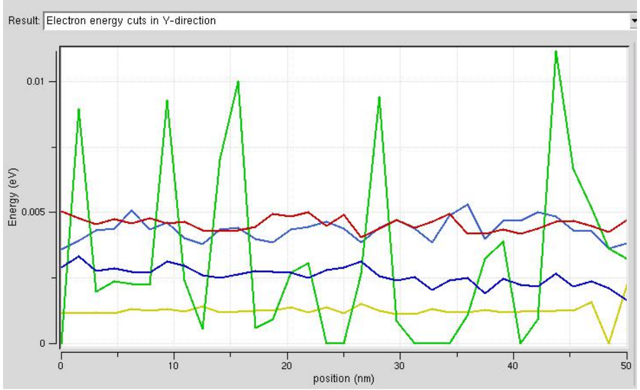

Fig.30 Electron Energy Cuts in Y-direction[9]

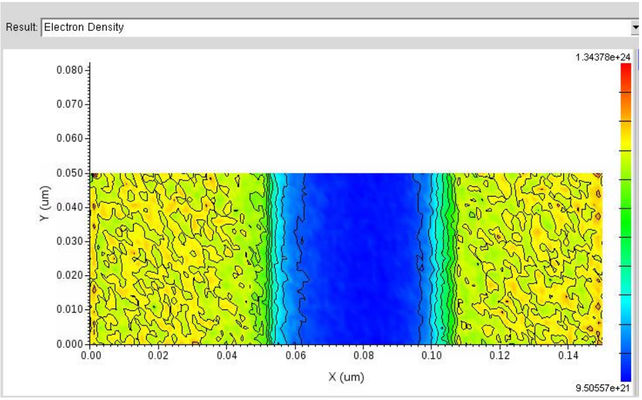

Fig.31 Electron Density[9]

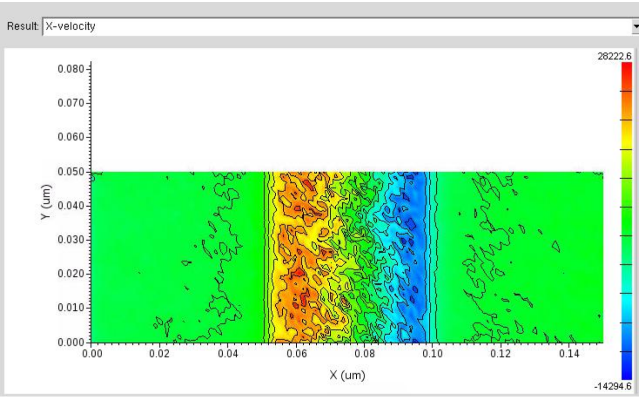

Fig.32 X-velocity[9]

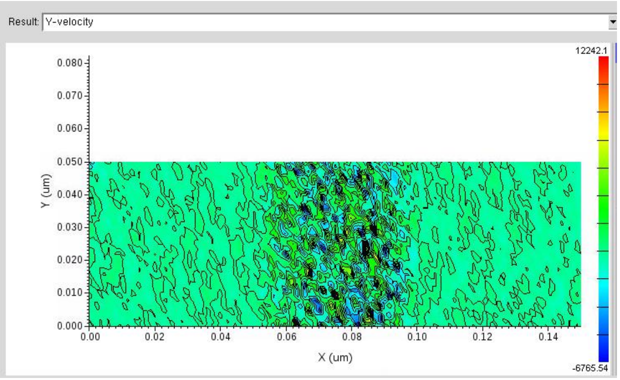
Result: Y-velocity

Fig.33 Y-velocity[9]

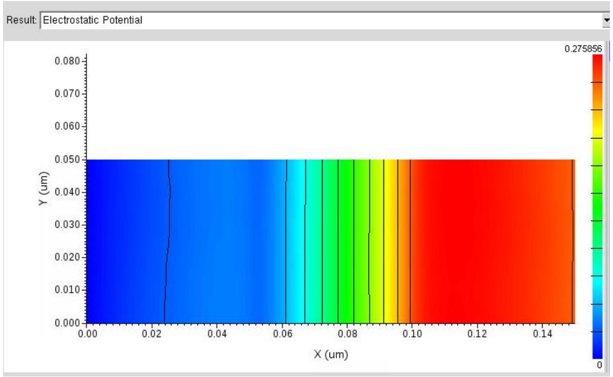
Result: Electrostatic Potential

Fig.34 Electrostatic Potential[9]

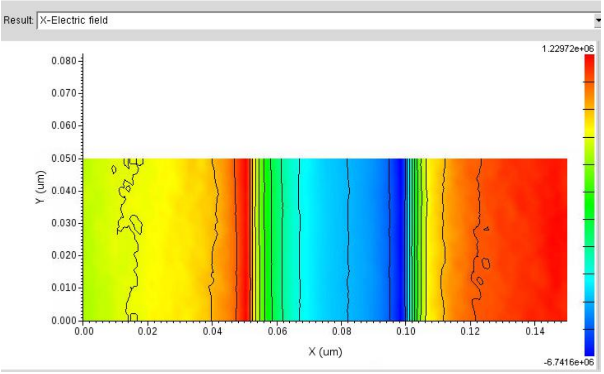
Result: X-Electric field

Fig.35 X- Electric Field[9]

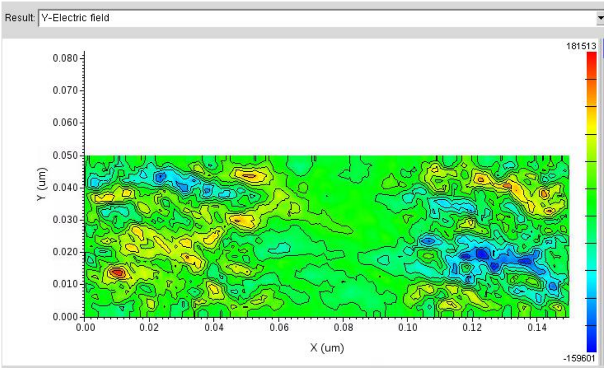
Result: Y-Electric field

Fig.36 Y- Electric Field[9]

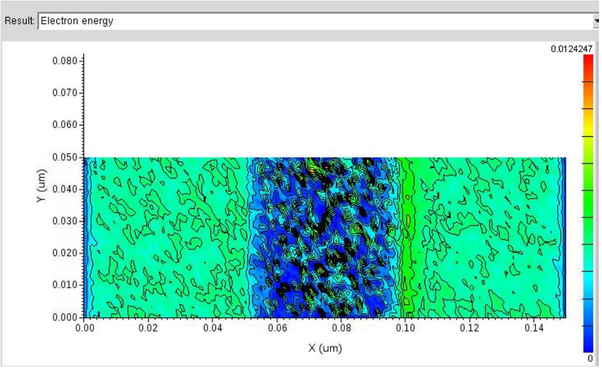
Result: Electron energy

Fig. 37 Electron Energy[9]

Notes:
Material: GaAs
Applied Bias: 0.25V
Lattice Temperature: 300K
Diode Geometry
L1: 50nm
LC: 50nm
L2: 50nam
Height: 50nm
Doping
N+(1/cm3): 1.0e18
N (1/cm3): 1.0e16

5 Graphene Field Effect Transistor (GFET) Design through Carbon Nanotube

The reason of utilizing Graphene field-effect transistors (GFETs) is to decrease short-channel impacts, and to enhance execution of transistors in length scales. The utilization of semiconducting graphene is vital given that metallic nanotubes can't be completely turned off. The principle preferences of this sort of transistors are: ballistic electron transport over its lengths, higher current thickness, bring down power utilization regarding silicon forms, and quicker operation speed.

Carbon nanotube based field effect transistors (FETs) have working attributes that are practically identical with those components in light of silicon. The dynamic part in field-effect transistors is the electrical channel built up by methods for the carbon nanotube in substrate interfacing source and deplete terminals. SWNTs have been the perfect competitors as semiconducting materials because it can be doped to address the kind of conductivity either n-sort or p-sort. Along these lines, they can control the level of electrical conduction. The carbon nanotube-based FETs can accomplish high pick up units (> 10), a substantial on-off proportion (>105), and room temperature operation[10]

Below are the characteristics of Graphene Field Effect Transistors are plotted (Fig. 38).

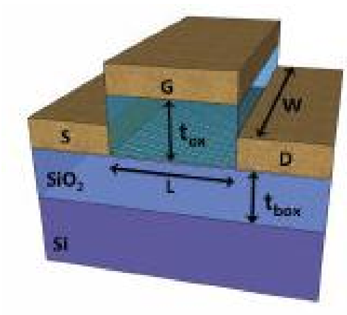

Fig.38 Isometric View of the Graphene Field Effect Transistor[10]

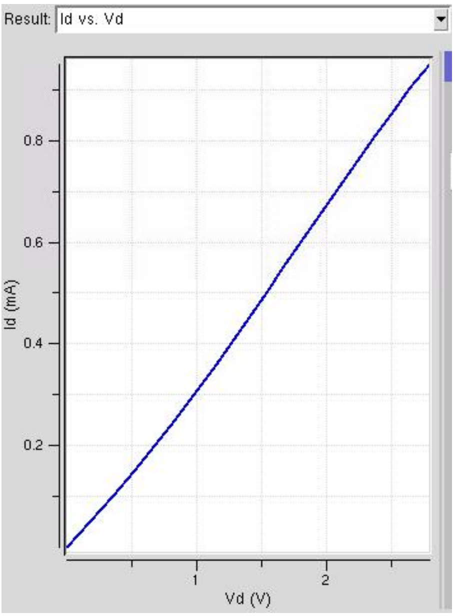

Fig.39 Depicts the Drain Current versus Drain Voltage (I_d vs V_d)[10]

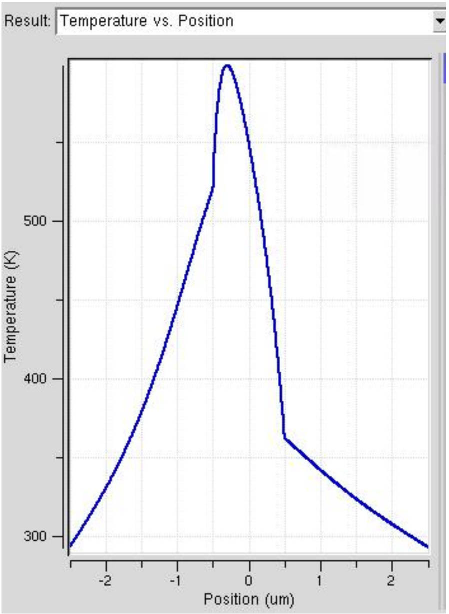

Fig.40 Depicts the Temperature versus Position[10]

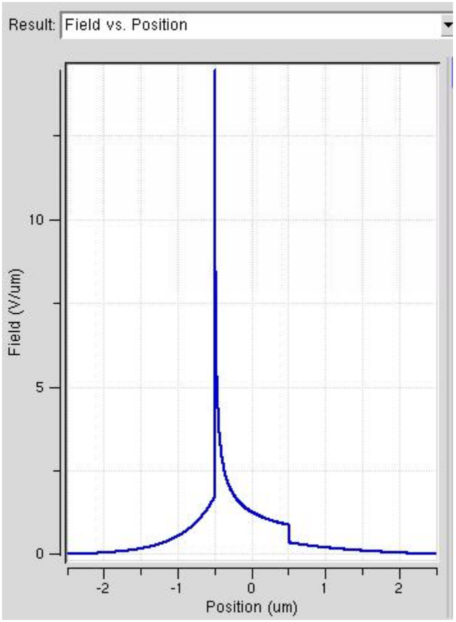

Fig.41 Depicts the Field versus Position[10]

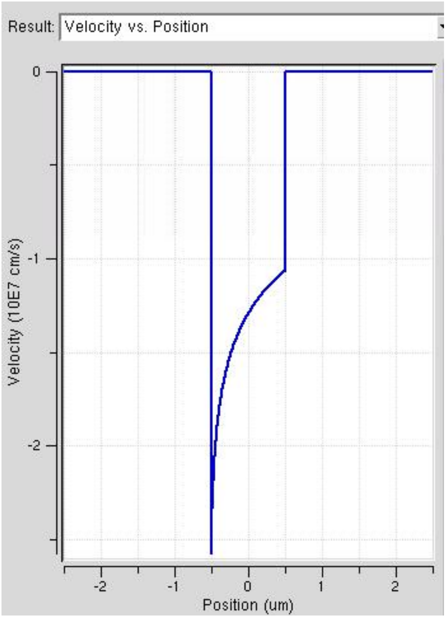

Fig.42 Depicts the Velocity versus Position[10]

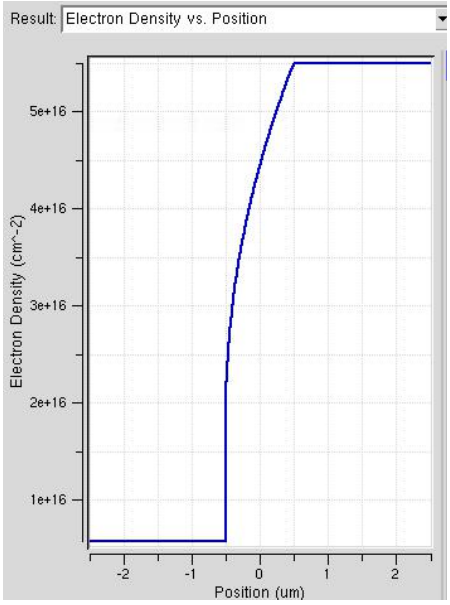

Fig.43 Depicts the Electron Density versus Position[10]

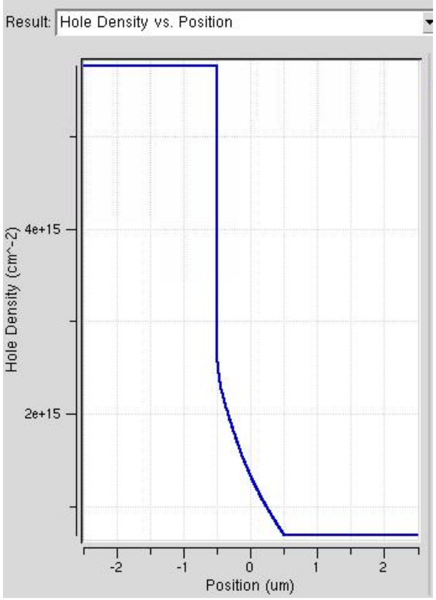

Fig.44 Depicts the Hole Density versus Position[10]

Notes:
Width: 1e-06m
Length: 1e-06m
Initial Temperature: 293K
Gate voltage: 0V
Dirac Voltage: 0V
Maximum Drain Current (A): 1e-3
Drain Current Step: 50e-6
Top Gate Oxide Thickness: 1e-08m
Mobility: 3000
Breakdown Temperature: 873K
Back Gate Oxide Thickness: 3e-07m
Metal Contact Resistance: 350
Thermal Conductivity of Insulator: 1.3
Thermal Conductivity of Wafer Substrate: 100
Thermal Conductivity of Graphene: 1000
Puddle Charge Density: 5e15

6 Date Analysis

Data Analysis was performed for Gallium Arsenide (GaAs) p-n junction at nano level data with 514 points. Graphs are plotted for Band Structures, Current, Density and Materials.

Band Structures

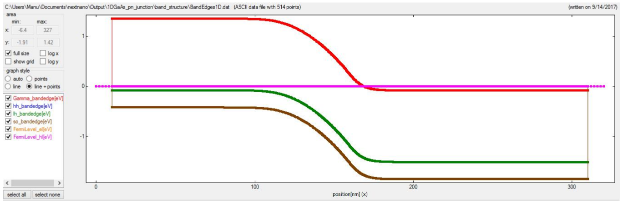

Fig.45 Depicts Band Edges[11]

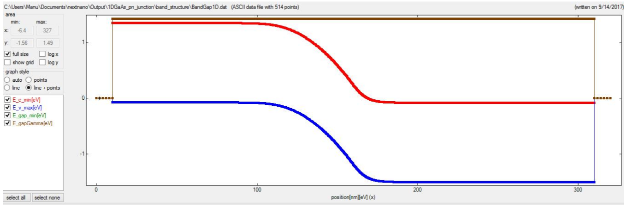

Fig.46 Depicts Band Gap[11]

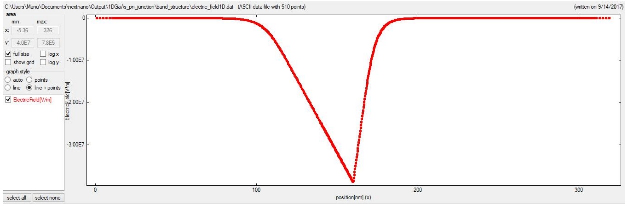

Fig.47 Depicts Electric Field[11]

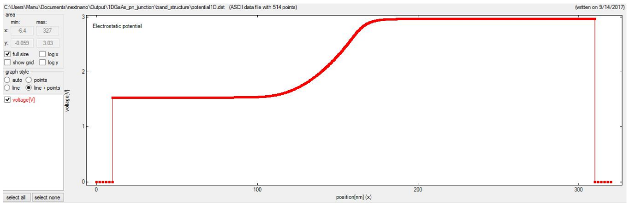

Fig.48 Depicts Potential[11]

Current

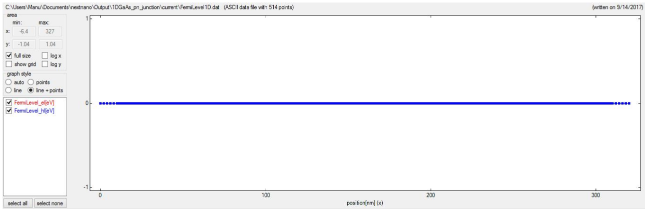
C:\Users\Manu\Documents\nextnano\Output\1DGaAs_pn_junction\current\FermiLevel1D.dat (ASCII data file with 514 points) (written on 9/14/2017)

Fig.49 Depicts Fermi Level[11]

Density

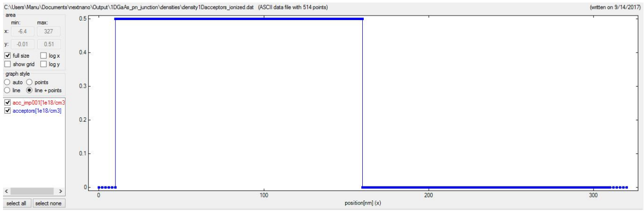
C:\Users\Manu\Documents\nextnano\Output\1DGaAs_pn_junction\densities\density1Dacceptors_ionized.dat (ASCII data file with 514 points) (written on 9/14/2017)

Fig.50 Depicts Acceptors[11]

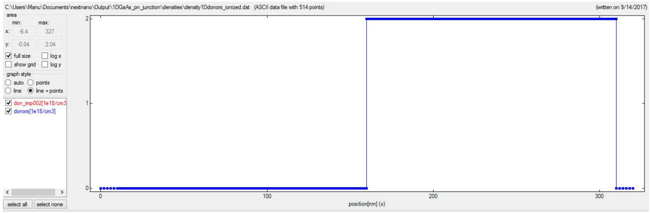
C:\Users\Manu\Documents\nextnano\Output\1DGaAs_pn_junction\densities\density1Ddonors_ionized.dat (ASCII data file with 514 points) (written on 9/14/2017)

Fig.51 Depicts Donors[11]

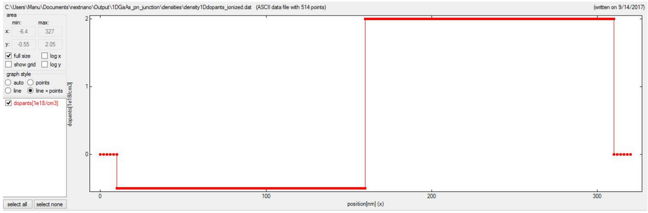
C:\Users\Manu\Documents\nextnano\Output\1DGaAs_pn_junction\densities\density1Ddopants_ionized.dat (ASCII data file with 514 points) (written on 9/14/2017)

Fig.52 Depicts Dopants[11]

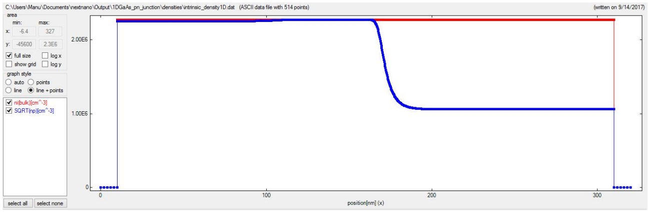
C:\Users\Manu\Documents\nextnano\Output\1DGaAs_pn_junction\densities\intrinsic_density1D.dat (ASCII data file with 514 points) (written on 9/14/2017)

Fig.53 Depicts Intrinsic Density[11]

Material

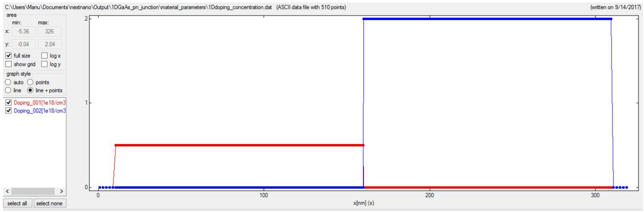
C:\Users\Manu\Documents\nextnano\Output\1DGaAs_pn_junction\material_parameters\1Ddoping_concentration.dat (ASCII data file with 510 points) (written on 9/14/2017)

Fig.54 Depicts Doping Concentration[11]

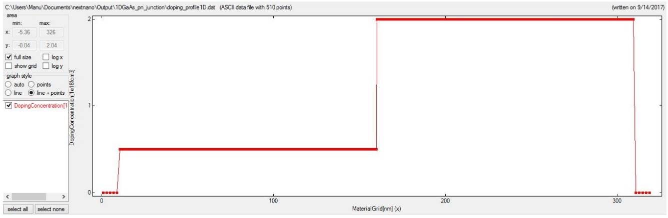
C:\Users\Manu\Documents\nextnano\Output\1DGaAs_pn_junction\doping_profile1D.dat (ASCII data file with 510 points) (written on 9/14/2017)

Fig. 55 Depicts Doping Profile[11]

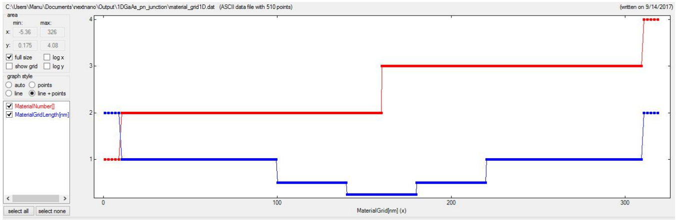
C:\Users\Manu\Documents\nextnano\Output\1DGaAs_pn_junction\material_grid1D.dat (ASCII data file with 510 points) (written on 9/14/2017)

Fig.56 Depicts Material Grid[11]

Interpretation of Graphs

Based on the graphs that are represented here; should be considered while designing a GaAs p-n junction using carbon nanotubes.

7 Applications and Advantages

7.1 Applications

There are many applications of carbon nanotubes such as usage in nano electronics, nano transistors and nano electronic components.

Large structures of carbon nanotubes can be used for thermal management of electronic circuits. An approximately 1 mm–thick carbon nanotube layer can be used to fabricate coolers. This material has very low density, ~20 times lower weight than a similar copper structure, while the cooling properties are similar for the two materials[12].

Another application is nanowire-based nano photonic devices, including light emitting diodes, lasers, solar cells, thermoelectric devices, and photodetectors[13].

7.2 Advantages

Building transistors from carbon nanotubes enables minimum transistor dimensions of a few nanometers and the development of techniques to manufacture integrated circuits built with nanotube transistors.

Conclusion

What is claimed in this are

An Electronic materials and its characteristics such as total energy, density of states, electron occupation statistics, Initial Atomic structure which is constructed from carbon nanotube are plotted.

A molecular Dynamics of nanomaterials and it’s characteristics such as Total Potential Energy, Kinetic Energy vs time, Temperature vs Time, Pressure vs Time, Volume vs Time, xx Stress Tensor vs Time, yy Stress Tensor component vs Time, zz Stress Tensor vs Time, zy Stress Tensor vs Time, zx Stress Tensor vs Time, xy Stress Tensor vs Time, Atomic Structure at 1.0 ps are plotted.

A Heterojunction carbon nanotubes and its characteristics like Density of States, Transmission functions are plotted.

A Electronic component of diode and its characteristics like Conduction Band in X-direction, Conduction Band in Y-direction, Electron density cuts in X-direction, Electron density cuts in Y-direction, Potential cuts in X-direction, Potential cuts in Y-direction, Electron energy cuts in X-direction, Electron energy cuts in Y-direction, Electron density, X-velocity, Y-velocity, Electrostatic potential, X-Electric field, Y-Electric field, Electron energy are plotted.

An electronic component Graphene Field Effect Transistor (GFET) and its characteristics such as Drain current vs drain voltage, Temperature versus position, Field versus Position, Velocity versus position, Electron density versus position, Hole density versus position are plotted

Data Analysis of Gallium Arsenide (GaAs) p-n junction at nano level data of 514 points and it's characteristics like Band Edges, Band Gap, Electric Field, Potential, Fermi Level, Acceptors, Donors, Dopants, Intrinsic density, Doping concentration, Doping profile, material grid are plotted

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References

[1] Allsopp, M., Santillo, D., & Walters, A. (2007, December). Nanotechnologies and nanomaterials in electrical and electronic goods: A review of uses and health concerns. Retrieved from http://www.greenpeace.to/publications/nanotech_in_electronics_2007.pdf

[2] Manufacturing at the Nanoscale. (n.d.). Retrieved fromhttps://www.nano.gov/nanotech-101/what/Manufacturing

[3] Joe Ringgenberg; Joydeep Bhattacharjee; Jeffrey B. Neaton; Jeffrey C Grossman (2016), "CNT Heterojunction Modeler," https://nanohub.org/resources/heterojunction.(DOI:10.4231/D3Q23R18W)

[4] Garber, C. (2007, November 15). Nanotechnology circuit boards. Retrieved from https://www.nanowerk.com/spotlight/spotid=3316.php

[5] nanoMATERIALS SeqQuest DFT [Online] Available: Ravi Pramod Kumar Vedula; Greg Bechtol; Benjamin P Haley; Alejandro Strachan (2016), "nanoMATERIALS SeqQuest DFT," https://nanohub.org/resources/nmst_dft. (DOI:10.4231/D3K931744).

[6] Rafael Vargas-Bernal and Gabriel Herrera-Pérez (2012). Carbon Nanotube- and Graphene Based Devices, Circuits and Sensors for VLSI Design, VLSI Design, Dr. Esteban Tlelo-Cuautle (Ed.), ISBN: 978-953-307-884-7, InTech, Available from: http://www.intechopen.com/books/vlsi-design/carbon-nanotube-and-graphenebased-devices-circuits-and-sensors-for-vlsi-design

[7] Alejandro Strachan; Amritanshu Palaria; Ya Zhou; Janam Jhaveri (2014), "nano-Materials Simulation Toolkit,"https://nanohub.org/resources/matsimtk.(DOI: 10.4231/D3416T079); "A general purpose code for molecular dynamics and coarse grain simulations," Alejandro Strachan, unpublished

[8] Joe Ringgenberg; Joydeep Bhattacharjee; Jeffrey B. Neaton; Jeffrey C Grossman (2016), "CNT Heterojunction Modeler,"

https://nanohub.org/resources/heterojunction.(DOI:10.4231/D3Q23R18W).

[9] Jean Michel D Sellier (2014), "Archimedes, GNU Monte Carlo simulator," https://nanohub.org/resources/archimedes.(DOI:10.4231/D3D21RK2M);www.gnu.org/software/archimedes http://arxiv.org/abs/1207.6575

[10] Eric Pop; Feifei Lian (2014), "GFET Tool," https://nanohub.org/resources/gfettool.(DOI:10.4231/D3QF8JK5T).

[11] Nextnano-Software for semiconductor nanodevices. (n.d.). Retrieved from http://nextnano.com/

[12] Potential applications of carbon nanotubes. (2018, February 27). Retrieved from https://en.wikipedia.org/wiki/Potential_applications_of_carbon_nanotubes

[13] Nano-electronic devices and materials. (n.d.). Retrieved from https://www.mcgill.ca/ece/research/electronicdevices