# EXPLORING THE ELECTRICAL CONDUCTANCE OF GRAPHENE NANORIBBON AND CARBON NANOTUBES BY VARYING THE BUNDLE WIDTH AND LENGTH TO OPTIMIZE CONDUCTANCE.

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**Abstract**

**Aim**: Conductance of graphene nanoribbons and carbon nanotubes are simulated by varying the bundle width from 100 nm to 2000 nm with the step size of 100 nm. **Materials and Methods:** Electrical conductance of Carbon nanotubes (n=100) was compared with graphene nanoribbons (n=100) by varying bundle width of both materials carbon nanotubes and graphene nanoribbons ranging from 100 nm to 2000 nm concerning the length ranging from 2 µm to 10 µm with the step size of 2 µm for each interval of the bundle width in the NANO HUB tool simulation environment. The pre-testing analysis was performed using clinicalc.com with G-power set to 85%, the threshold set to 0.05 for each group, and the sample size set to 100. **Results**: Graphene nanoribbons have significantly higher conductance (120.487 mho, P<0.001) than carbon nanotubes (31.364 mho, P<0.001). The optimal bundle width for the maximum conductivity is 2000 nm for Carbon nanotubes and graphene nanoribbons. **Conclusion:** Within the scope of this study, Graphene nanoribbons with a bundle width of 2000 nm offer the best conductivity.

**Keywords:** Novel graphene nanoribbons, Carbon nanotubes, Bundle width, Nanomaterial, Nanoelectronics

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## 1. Introduction

The conductance of nanomaterials such as Novel graphene nanoribbons and Carbon nanotubes are being explored through simulation by varying the bundle width and length of the device. Carbon nanotubes and novel graphene nanoribbons are vital for improving the bulk polymer's mechanical, thermal, current, and voltage characteristics. (Todri-Sanial, Dijon, and Maffucci 2016). There are many applications for graphene nanoribbons some of the examples are Liquid crystals, Schottky diodes, Transparent conductive electrodes, Solar cell systems, Light emitting diodes, Field effect transistors, etc. (Katsnelson 2020). Examples for the application of Carbon nanotubes are carbon nanotubes based air, water filtration, thermal conductivity, energy storage, carbon nanotubes based MOSFETs, carbon nanotube biomedical applications, etc (Amin, Kumar, and Belharouak 2020).

In the past five years, several articles published in the field of nanoelectronics such as Carbon nanotubes 64 journal papers published in the IEEE explore and 1980 research articles were published in science direct and google scholar. Graphene nanoribbons feature low electrical resistivity, excellent thermal conductivity, and high current and voltage carrying capabilities, making graphene a viable alternative for replacing conventional materials in the fabrication of VLSI nano-interconnects. (Todri-Sanial, Dijon, and Maffucci 2016; Tiwari and Shukla 2014).Graphene nanoribbons are of potential use in the development of electronic and optoelectronic devices (Song and Zeng 2015). GNR shows a bandgap that can be tuned by tailoring its width and edge structure. Zigzag GNRs are always metallic, while armchair GNRs can be either metallic or semiconducting (Kausar 2021). Carbon nanotubes and novel graphene nanoribbons have both demonstrated excellent results in terms of thermal management, RC delay, and conductance at one or more interconnect levels. (Soldano, Talapatra, and Kar 2013).

Our institution is passionate about high quality evidence based research and has excelled in various domains (Vickram et al. 2022; Bharathiraja et al. 2022; Kale et al. 2022; Sumathy et al. 2022; Thanigaivel et al. 2022; Ram et al. 2022; Jothi et al. 2022; Anupong et al. 2022; Yaashikaa, Keerthana Devi, and Senthil Kumar 2022; Palanisamy et al. 2022).Downsizing elements to less than 100 nm in size, as well as connectivity, present numerous significant obstacles. As the interconnect, dimensions approach the lateral dimension, grain boundary scattering, surface scattering, and a high resistivity diffusive barrier layer increase the total resistivity. This study aims to determine the best carbon allotropy such as carbon nanotubes or graphene nanoribbons for interconnecting applications and replace the conventional copper interconnect with it.

## 2. Material and Methods

This study was carried out at the Saveetha University, nano hub simulation lab, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai. In this research, there are two groups in this study. Group 1 refers to carbon nanotubes, whereas Group 2 refers to novel graphene nanoribbons. The pre-testing analysis was performed using clinicalc.com with G-power set to 85%, the threshold set to 0.05 for each group, and the sample size set to 100. The overall sample size for the study project is 200, with an 80 percent pre-test power analysis. (Todri-Sanial, Dijon, and Maffucci 2016).

To prepare the sample for group 1, the bundle width is varied from 100 nm to 2000 nm using the nano hub tool at 100 nm step size, in order to analyze the electrical conductance of carbon nanotubes. To simulate the carbon nanotube conductance first open the Nano Hub in any one of the available search engines. Select the resources in the Nano hub home page then select the carbon in tags and select carbon nanotube interconnect in the next box and click on launch in the next box. After launching the tool select the carbon nanotube interconnects from the drop-down box, then go to the structure and vary the bundle width. For each change on the bundle width with an interval of 100 nm, select on simulating to get results for the respective values.

To prepare the sample for group 2, the bundle width is varied from 100 nm to 2000 nm using the nano hub tool at 100 nm step size, in order to analyze the electrical conductance of graphene nanoribbons. Similar to the sample preparation of group one, select the graphene nano to interconnect from the drop-down box, then go to the structure to vary the bundle width. For each change on the bundle width with an interval of 100 nm, select simulating to get the results based on the respective values.

Nano hub consists of standard commercial nanoelectronics software packages which are simulation tools based on research as well as tutorials, and courses. Nano Hub is an open-source simulation tool. It produces precise, accurate findings since it is a software tool (Klimeck et al. 2011). Carbon nanotubes and graphene nanoribbons are analyzed for their current-voltage characteristics. Keep the height as the constant ( h = 100 nm ) and note down the conductance from the plot obtained during simulation, concerning the length. Do the same procedure for both the carbon nanotube and graphene nanoribbons. The conductance of the carbon nanotubes and novel graphene nanoribbons are obtained.

**Statical analysis**

Origin and SPSS were the statistical tools used in this study. Plotting graphs for input values and comparing variables is done using Origin while determining the mean, standard deviation, and significant difference is done using SPSS (Landau 2017). In this study, the bundle width and length are independent variables because they are inputs and remain constant even after the other parameters are changed, but the conductance is a dependent variable since it depends on the inputs and varies with each change in the input. This study's analysis is based on an independent T-Test that compares the conductivity of carbon nanotubes and graphene nanoribbons.

## 3. Results

Current-voltage characteristics of nanomaterials such as carbon nanotubes and graphene nanoribbons for the bundle width (50 nm to 1000 nm) are shown in Fig. 1 and Fig. 2 respectively. For every change in the bundle width of the device, conductance is tabulated by keeping the height of the bundle constant 100 nm. Table 1 and Table 2 refer to carbon nanotubes, In which Table 1 ranges from 100 nm to 1200 nm, Table 2 ranges from1300 nm to 2000 nm. Table 3 and Table 4 refer to graphene nanoribbons, In which Table 3 ranges from 100 nm to 800 nm, Table 4 ranges from 900 nm to 2000 nm. Fig. 1 and Fig. 2 represent the conductivity of the carbon nanotubes and novel graphene nanoribbons respectively. Fig. 3 represents the comparison graph of conductance of carbon nanotubes and novel graphene nanoribbons. Fig. 4 represents the bar chart comparing the mean (+/- 1SD) conductance of carbon nanotubes and graphene nanoribbons. From Table 1 and Table 2 the conductivity of carbon nanotubes was maximum when bundle width is 2000 nm and bundle length is 2 µm which is 31.3647 mho. From Table 3 and Table 4 the conductivity of the graphene nanoribbons was maximum when the bundle width is 2000 nm and bundle length is 2 µm which is 120.487 mho.

Conductivity of the nanomaterial such as carbon nanotubes and graphene nanoribbons was increasing with the increase in the bundle width and decreases with the decrease in the bundle length because there is an increase in the number of free electrons on the surface with greater bundle width, resulting in improved electrical conductivity. From Fig. 3 graphene nanoribbons are more conductible than carbon nanoribbons at the same bundle width.

There is a statistically significant difference between the conductance of the nanomaterial such as carbon nanotubes and graphene nanoribbons since the value of p is less than 0.001 ($p<0.001$) from table 6. From table 5 the average conductance of the carbon nanotubes is 10.399022 is less than the average conductance of the Novel graphene nanoribbons of 14.577580, which indicates that graphene has better conductivity than carbon nanotubes.

## 4. Discussion

The conductivity of novel graphene nanoribbons and carbon nanotubes is explored by altering the device's bundle width. The electrical conductance characteristics have been simulated for different bundle widths of the device ranging from 100 nm to 2000 nm with a step size of 100 nm. After evaluating the simulation curves, it was found that an increase in the bundle width causes increases in the conductance for both carbon nanotubes and graphene nanoribbons, and graphene nanoribbons (120.487 mhos) has better electrical conductivity than the carbon nanotubes (31.364 mhos) for the maximum 2000 nm of bundle width.

Hassen Dakhlaoui and Shaffa Almansour have researched the conductivity of graphene nanoribbons with multiple barriers when a voltage is supplied. The researcher concluded that the Electronic conductance of graphene nanoribbons is sensitive to the number of carbon atoms and external voltage and current in them, which allows us to tailor the electronic properties of the graphene-based devices (Wong et al., n.d.). The current conductance of graphene nanoribbons strongly depends on the structure of the graphene (zigzag and armchair) conductance of zigzag and armchair structured graphene nanoribbons V = 1.0 eV and V = 0. eV respectively with a constant length of 14nm. Graphene nanoribbons can be either semiconducting or metallic, it depends on the shape. As a result, GNRs can be implemented as both a functional element and a connector in nanodevices, since it has better current and voltage properties (Gorjizadeh, Farajian, and Kawazoe 2009). The growing interest in graphene nano-interconnects drives the search for more precise and efficient models that can account for all quantum effects. such as quantum conductance, quantum capacitance, etc arising at the nanoscale (Lopes, Santos, and Bueno 2021). Giovanni Miano and Antonio Maffucci have researched the current and voltage properties of graphene for interconnect applications (Maffucci, Miano, and Villone 2008)

in the field of nanoelectronics. In nanotechnology, where a few hundreds or thousands of atoms are involved, It is crucial to analyze the nature of interfaces and any potential dynamics that happen at an interface. (Todri-Sanial, Dijon, and Maffucci 2016; Soldano, Talapatra, and Kar 2013).
Factors affecting nanomaterials such as graphene nanoribbons are Novel GNRs that have two open edges at both sides in their structure; this boundary structure makes GNRs more vulnerable to defects than carbon nanotubes. Every GNRs contains local defects or extended disorders, whereas graphene sheets commonly contain few defects (Soldano, Talapatra, and Kar 2013). The limitations to this study are the width of a graphene nanoribbon and a carbon nanotube cannot be increased over 1000 nm (Gorjizadeh, Farajian, and Kawazoe 2009).
Copper, which is currently employed as an interconnecting material, is affected by two major issues: One is due to its inability to handle high current density, while the other is due to higher electrical resistance caused by surface dispersion of electronics, as well as issues caused by grain boundaries. In the future, the problems with copper interconnect can be overcome by replacing the copper interconnect with graphene interconnect for better conductivity and thermal performance.

## 5. Conclusion

Graphene nanoribbons have significantly higher conductance (120.487 mho, $p<0.001$) than carbon nanotubes (31.3647 mhos, $p<0.001$). Conductivity increases with increasing width in graphene nanoribbons and carbon nanotubes, so the bundle width should be maximum for optimal conductance.

**Declarations**

**Conflict of Interest**

No conflict of interest in this manuscript.

**Author Contribution**

Author KP was involved in data collection, data analysis, and manuscript writing. Author DA was involved in the conceptualization, guidance, and critical review of the manuscript.

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## 6. References

Amin, Ruhul, Petla Ramesh Kumar, and Ilias Belharouak. 2020. “Carbon Nanotubes: Applications to Energy Storage Devices.” Carbon Nanotubes - Redefining the World of Electronics [Working Title]. https://doi.org/10.5772/intechopen.94155.

Anupong, Wongchai, Lin Yi-Chia, Mukta Jagdish, Ravi Kumar, P. D. Selvam, R. Saravanakumar, and Dharmesh Dhabliya. 2022. “Hybrid Distributed Energy Sources Providing Climate Security to the Agriculture Environment and Enhancing the Yield.” Sustainable Energy Technologies and Assessments. https://doi.org/10.1016/j.seta.2022.102142.

Bharathiraja, B., J. Jayamuthunagai, R. Sreejith, J. Iyyappan, and R. Praveenkumar. 2022. “Techno Economic Analysis of Malic Acid Production Using Crude Glycerol Derived from Waste Cooking Oil.” Bioresource Technology 351 (May): 126956.

Gorjizadeh, Narjes, Amir A. Farajian, and Yoshiyuki Kawazoe. 2009. “The Effects of Defects on the Conductance of Graphene Nanoribbons.” Nanotechnology 20 (1): 015201.

Jothi, K. Jeeva, K. Jeeva Jothi, S. Balachandran, K. Mohanraj, N. Prakash, A. Subhasri, P. Santhana Gopala Krishnan, and K. Palanivelu. 2022. “Fabrications of Hybrid Polyurethane-Pd Doped ZrO2 Smart Carriers for Self-Healing High Corrosion Protective Coatings.” Environmental Research. https://doi.org/10.1016/j.envres.2022.113095.

Kale, Vaibhav Namdev, J. Rajesh, T. Maiyalagan, Chang Woo Lee, and R. M. Gnanamuthu. 2022. “Fabrication of Ni–Mg–Ag Alloy Electrodeposited Material on the Aluminium Surface Using Anodizing Technique and Their Enhanced Corrosion Resistance for Engineering Application.” Materials Chemistry and Physics. https://doi.org/10.1016/j.matchemphys.2022.125900.

Katsnelson, Mikhail I. 2020. The Physics of Graphene. Cambridge University Press.

Kausar, Ayesha. 2021. Graphene to Polymer/Graphene Nanocomposites: Emerging Research and Opportunities. Elsevier.

Klimeck, Gerhard, George B. Adams III, Krishna

P. C. Madhavan, Nathan Denny, Michael G. Zentner, Swaroop Shivarajapura, Lynn K. Zentner, and Diane L. Beaudoin. 2011. "Social Networks of Researchers and Educators on nanoHUB.org." 2011 11th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing. https://doi.org/10.1109/ccgrid.2011.33.

Landau, Sabine. 2017. A Handbook of Statistical Analysis Using SPSS. Chapman & Hall/CRC.

Lopes, Laís C., Adriano Santos, and Paulo R. Bueno. 2021. "Measuring Quantum Conductance and Capacitance of Graphene Using Impedance-Derived Capacitance Spectroscopy." Carbon. https://doi.org/10.1016/j.carbon.2021.08.055.

Maffucci, A., G. Miano, and F. Villone. 2008. "Electromagnetic and Circuital Modeling of Carbon Nanotube Interconnects." 2008 2nd Electronics Systemintegration Technology Conference. https://doi.org/10.1109/estc.2008.4684497.

Palanisamy, Rajkumar, Diwakar Karuppiah, Subadevi Rengapillai, Mozaffar Abdollahifar, Gnanamuthu Ramasamy, Fu-Ming Wang, Wei-Ren Liu, Kumar Ponnuchamy, Joongpyo Shim, and Sivakumar Marimuthu. 2022. "A Reign of Bio-Mass Derived Carbon with the Synergy of Energy Storage and Biomedical Applications." Journal of Energy Storage. https://doi.org/10.1016/j.est.2022.104422.

Ram, G. Dinesh, G. Dinesh Ram, S. Praveen Kumar, T. Yuvaraj, Thanikanti Sudhakar Babu, and Karthik Balasubramanian. 2022. "Simulation and Investigation of MEMS Bilayer Solar Energy Harvester for Smart Wireless Sensor Applications." Sustainable Energy Technologies and Assessments. https://doi.org/10.1016/j.seta.2022.102102.

Soldano, Caterina, Saikat Talapatra, and Swastik Kar. 2013. "Carbon Nanotubes and Graphene Nanoribbons: Potentials for Nanoscale Electrical Interconnects." Electronics. https://doi.org/10.3390/electronics2030280.

Song, Jizhong, and Haibo Zeng. 2015. "Transparent Electrodes Printed with Nanocrystal Inks for Flexible Smart Devices." Angewandte Chemie 54 (34): 9760–74.

Sumathy, B., Anand Kumar, D. Sungeetha, Arshad Hashmi, Ankur Saxena, Piyush Kumar Shukla, and Stephen Jeswinde Nuagah. 2022. "Machine Learning Technique to Detect and Classify Mental Illness on Social Media Using Lexicon-Based Recommender System." Computational Intelligence and Neuroscience 2022 (February): 5906797.

Thanigaivel, Sundaram, Sundaram Vickram, Nibedita Dey, Govindarajan Gulothungan, Ramasamy Subbaiya, Muthusamy Govarthanan, Natchimuthu Karmegam, and Woong Kim. 2022. "The Urge of Algal Biomass-Based Fuels for Environmental Sustainability against a Steady Tide of Biofuel Conflict Analysis: Is Third-Generation Algal Biorefinery a Boon?" Fuel. https://doi.org/10.1016/j.fuel.2022.123494.

Tiwari, Ashutosh, and S. K. Shukla. 2014. Advanced Carbon Materials and Technology. John Wiley & Sons.

Todri-Sanial, Aida, Jean Dijon, and Antonio Maffucci. 2016. Carbon Nanotubes for Interconnects: Process, Design and Applications. Springer.

Vickram, Sundaram, Karunakaran Rohini, Krishnan Anbarasu, Nibedita Dey, Palanivelu Jeyanthi, Sundaram Thanigaivel, Praveen Kumar Issac, and Jesu Arockiaraj. 2022. "Semenogelin, a Coagulum Macromolecule Monitoring Factor Involved in the First Step of Fertilization: A Prospective Review." International Journal of Biological Macromolecules 209 (Pt A): 951–62.

Wong, Bryan, Hassen Dakhlaoui, Shaffa Almansour, and Walid Belhadj. n.d. "Modulating the Conductance in Graphene Nanoribbons with Multi-Barriers Under an Applied Voltage." https://doi.org/10.33774/chemrxiv-2021-320dd.

Yaashikaa, P. R., M. Keerthana Devi, and P. Senthil Kumar. 2022. "Algal Biofuels: Technological Perspective on Cultivation, Fuel Extraction and Engineering Genetic Pathway for Enhancing Productivity." Fuel. https://doi.org/10.1016/j.fuel.2022.123814.

Dey, N., Kumar, G., Vickram, A. S., Mohan, M., Singhania, R. R., Patel, A. K., ... & Ponnusamy, V. K. (2022). Nanotechnology-assisted production of value-added biopotent energy-yielding products from lignocellulosic biomass refinery–a review. Bioresource Technology, 344, 126171.

**Tables and figure**

Table 1. Conductivity of carbon nanotubes by varying the width ranging from 100 nm to 1200 nm, In which the highest conductivity is 18.9 mho at 1200 nm width and 2 µm length**.**

| width (nm) | Length (μm) | Conductance (mho) | Width (nm) | length (μm) | conductance(mho) | Width (nm) | Length (μm) | Conductance(mho) | Width (nm) | Length (μm) | Conductance (mho) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 1.51765 | | 2 | 3.12 | | 2 | 4.17157 | | 2 | 6.23922 |
| | 4 | 1.23062 | | 4 | 2.5299 | | 4 | 3.8286 | | 4 | 5.055922 |
| 100 | 6 | 0.871644 | 200 | 6 | 1.7919 | 300 | 6 | 2.7117 | 400 | 6 | 3.58343 |
| | 8 | 0.654209 | | 8 | 1.3449 | | 8 | 2.03532 | | 8 | 2.58952 |
| | 10 | 0.523367 | | 10 | 1.0759 | | 10 | 1.62825 | | 10 | 2.15162 |
| | 2 | 7.84158 | | 2 | 9.35922 | | 2 | 10.9608 | | 2 | 12.5631 |
| | 4 | 6.35852 | | 4 | 7.58915 | | 4 | 8.88782 | | 4 | 10.171 |
| 500 | 6 | 4.50372 | 600 | 6 | 5.37536 | 700 | 6 | 6.29521 | 800 | 6 | 7.2155 |
| | 8 | 3.38025 | | 8 | 4.17078 | | 8 | 4.72847 | | 8 | 5.41556 |
| | 10 | 2.7042 | | 10 | 3.22756 | | 10 | 3.77987 | | 10 | 4.33245 |
| | 2 | 14.0808 | | 2 | 15.6824 | | 2 | 17.2 | | 2 | 18.8024 |
| | 4 | 11.4177 | | 4 | 12.7164 | | 4 | 13.947 | | 4 | 15.2463 |
| 900 | 6 | 8.08715 | 1000 | 6 | 9.00699 | 1100 | 6 | 9.87863 | 1200 | 6 | 10.7989 |
| | 8 | 6.06977 | | 8 | 6.76015 | | 8 | 7.14436 | | 8 | 8.10509 |
| | 10 | 4.85582 | | 10 | 5.4081 | | 10 | 5.93149 | | 10 | 6.46407 |

Table 2. Conductivity of carbon nanotubes by varying the width ranging from 1300 nm to 2000 nm, In which the highest conductivity is 31.3 mho at 2000 nm width and 2 μm length.

| width (nm) | Length (μm) | Conductance (mho) | Width (nm) | length (μm) | conductance(mho) | Width (nm) | Length (μm) | Conductance(mho) | Width (nm) | Length (μm) | Conductance (mho) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 130 | 2 | 20.4039 | 140 | 2 | 21.9216 | 150 | 2 | 23.5239 | 160 | 2 | 25.1255 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 4 | 16.545 | 0 | 4 | 17.7756 | 0 | 4 | 19.0749 | 0 | 4 | 20.37336 |
| | 6 | 11.7188 | | 6 | 12.5940 | | 6 | 13.057 | | 6 | 14.4306 |
| | 8 | 8.79547 | | 8 | 9.44968 | | 8 | 10.1404 | | 8 | 10.8308 |
| | 10 | 7.043683 | | 10 | 7.5594 | | 10 | 8.11232 | | 10 | 8.66463 |
| 1700 | 2 | 26.6432 | 1800 | 2 | 28.2455 | 1900 | 2 | 29.7632 | 2000 | 2 | 31.3647 |
| | 4 | 21.6042 | | 4 | 22.9035 | | 4 | 34.1342 | | 4 | 25.4328 |
| | 6 | 15.3022 | | 6 | 16.2225 | | 6 | 17.0941 | | 6 | 18.014 |
| | 8 | 11.485 | | 8 | 12.1757 | | 8 | 12.8299 | | 8 | 13.5203 |
| | 10 | 9.188 | | 10 | 9.74057 | | 10 | 10.2639 | | 10 | 10.8162 |

Table 3. Conductivity of graphene nanoribbons by varying the width ranging from 100 nm to 800 nm, In which the highest conductivity is 6.8 mho at 800 nm width and 2 µm length.

| width (nm) | Length (µm) | Conductance (mho) | Width (nm) | length (µA) | conductance(mho) | Width (nm) | Length (µm) | Conductance(mho) | Width (nm) | Length (µm) | Conductance (mho) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 2 | 0.0481778 | 200 | 2 | 0.152025 | 300 | 2 | 0.16122 | 400 | 2 | 0.811162 |
| | 4 | 0.0240886 | | 4 | 0.076012 | | 4 | 0.180610 | | 4 | 0.40558 |
| | 6 | 0.012043 | | 6 | 0.050675 | | 6 | 0.120407 | | 6 | 0.21443 |
| | 8 | 0.011024 | | 8 | 0.038006 | | 8 | 0.090305 | | 8 | 0.20364 |
| | 10 | 0.011024 | | 10 | 0.015298 | | 10 | 0.072244 | | 10 | 0.01365 |
| 500 | 2 | 1.579344 | 600 | 2 | 2.77094 | 700 | 2 | 4.49186 | 800 | 2 | 6.84844 |
| | 4 | 0.789672 | | 4 | 1.385468 | | 4 | 2.24592 | | 4 | 3.42422 |
| | 6 | 0.59462 | | 6 | 0.923646 | | 6 | 1.497286 | | 6 | 2.2828 |
| | 8 | 0.394836 | | 8 | 0.554188 | | 8 | 1.122964 | | 8 | 1.7122 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 0.315868 | | 10 | 0.554188 | | 10 | 0.926475 | | 10 | 1.365484 |

Table 4. Conductivity of graphene nanoribbons by varying the width ranging from 900 nm to 2000 nm, In which the highest conductivity is 120.5 mho at 2000 nm width and 2 μm length.

| width (nm) | Length (μm) | Conductance (mho) | Width (nm) | length (μm) | conductance(mho) | Width (nm) | Length (μm) | Conductance(mho) | Width (nm) | Length (μm) | Conductance (mho) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 900 | 2 | 9.2876 | 1000 | 2 | 13.0968 | 1100 | 2 | 17.86408 | 1200 | 2 | 23.7116 |
| | 4 | 4.64938 | | 4 | 6.5484 | | 4 | 8.93204 | | 4 | 11.85578 |
| | 6 | 3.09958 | | 6 | 4.3656 | | 6 | 5.9547 | | 6 | 7.90386 |
| | 8 | 3.00259 | | 8 | 3.2742 | | 8 | 4.46602 | | 8 | 5.92788 |
| | 10 | 2.3619 | | 10 | 2.61936 | | 10 | 3.57282 | | 10 | 4.74232 |
| 1300 | 2 | 30.7548 | 1400 | 2 | 39.15743 | 1500 | 2 | 48.9534 | 1600 | 2 | 60.37383 |
| | 4 | 15.3772 | | 4 | 19.5675 | | 4 | 24.4766 | | 4 | 30.1818 |
| | 6 | 8.96234 | | 6 | 13.0448 | | 6 | 16.3177 | | 6 | 20.0606 |
| | 8 | 7.6888 | | 8 | 9.7834 | | 8 | 11.658 | | 8 | 16.9645 |
| | 10 | 6.154094 | | 10 | 6.9624 | | 10 | 9.65478 | | 10 | 11.3256 |
| 1700 | 2 | 70.7884 | 1800 | 2 | 85.378 | 1900 | 2 | 101.9106 | 2000 | 2 | 120.487 |
| | 4 | 35.1589 | | 4 | 42.689 | | 4 | 50.9554 | | 4 | 60.326 |
| | 6 | 23.5962 | | 6 | 28.4594 | | 6 | 33.9702 | | 6 | 40.1625 |
| | 8 | 17.6908 | | 8 | 21.5698 | | 8 | 25.4776 | | 8 | 30.1212 |
| | 10 | 14.15766 | | 10 | 17.0756 | | 10 | 20.3822 | | 10 | 24.0974 |

Table 5. Comparison of Drain conductance of carbon nanotubes and novel graphene nanoribbons. Carbon nanotubes have mean conductance of 10.399022. Graphene nanoribbons have mean conductance of 14.577580.

| | Group | N | Mean | std.Deviation | std.Error mean |
|---|---|---|---|---|---|
| conductance | Carbon nanotubes | 100 | 10.399022 | 7.34437461 | 0.7344376 |
| | Graphene nanoribbons | 100 | 14.577580 | 21.8920676 | 2.1892068 |

Table 6. T-test comparison of conductance of carbon nanotubes and novel graphene nanoribbons. Since $p < 0.001$, there is a considerable difference between the two groups (Independent sample T-Test).

| Leven's Test for Equality of variances | | | | | | Significance | | T-test for Equality of means | | 95% confidence interval of Difference | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| conductance | | F | Sig | t | df | One-sided p | Two-sided p | Mean Difference | Std. Error Difference | lower | upper |
| | Equal variances assumed | 30.419 | <0.001 | -1.810 | 198 | 0.036 | 0.072 | -4.1785583 | 2.3091178 | -8.7321789 | 0.3750623 |
| | Equal variances not assumed | | | -1.810 | 121.006 | 0.036 | 0.073 | -4.1785583 | 2.3091178 | -8.7500638 | 0.3929472 |

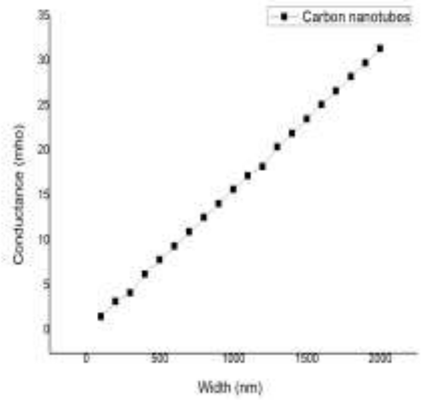


Fig. 1. Simulation of conductance of carbon nanotubes with widths ranging from 50 nm to 2000 nm. The black line represents the conductance of carbon nanotubes.

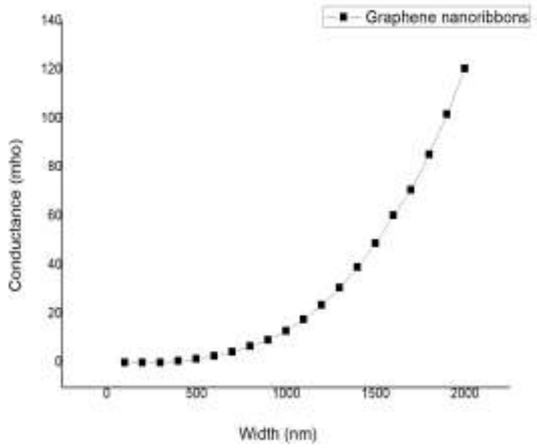


Fig. 2. Simulation of conductance of novel graphene nanoribbons with widths ranging from 50 nm to 2000 nm. The black line represents the conductance of graphene nanoribbons.

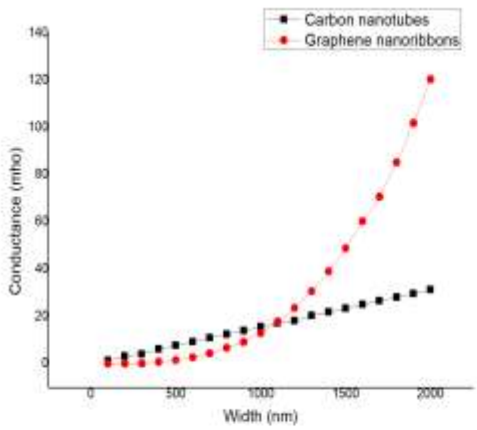


Fig. 3. comparison graph of conductance of carbon nanotubes and novel graphene nanoribbons. The Black line represents the carbon nanotubes and the Red line represents the graphene nanoribbons.

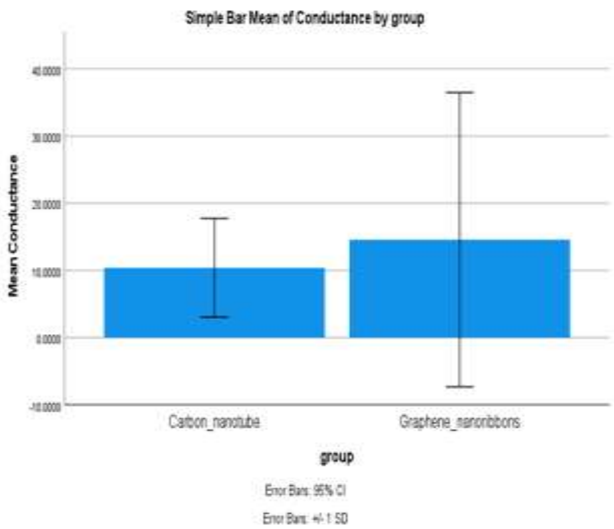


Fig. 4. Bar chart comparing the mean (+/- 1SD) conductance of carbon nanotubes and graphene nanoribbons. The mean conductance of novel graphene nanoribbons is better than carbon nanotubes. X-Axis: carbon nanotubes vs graphene nanoribbons. Y-Axis: Mean of conductance.