



Review Paper

# Electronic Properties of Graphene: A Co-author Bibliometric Analysis

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## Abstract

*Astonishing properties possessed by graphene has rewarded this carbon material a high pedestal. Graphene has an atom thick 2D honeycomb hexagonal structure of carbon atoms and has unique electronic properties. It is a zero-band gap material and shows integer quantum hall effect (IQHE) even at room temperature. Electronic properties of graphene offer low sheet resistance and high transmittance which is useful in the production of several electronic devices. Looking into the potential of electronic properties of graphene and the emerging literature a bibliometric study has been undertaken. The data for bibliometric analysis on electronic properties of graphene has been obtained from Web of Science (WOS) database from January 2004 to March 2025. Obtained data been analysed through the bibliometrix R package and VOS-viewer software. Metadata report as obtained through bibliometrix reveals excellent condition of all bibliometric parameters. Number of documents published under various WOS categories have been represented by a donut-chart. Published documents belonging to different categories have been shown through a pi-chart. A bar chart of publishers supporting the research on electronic properties of graphene has been presented. The chart shows that maximum number of documents have been published by Elsevier publishing house. Co-author, analysis has been performed to identify the collaboration among the authors, organizations and countries worldwide. Data has been analysed using different bibliometric indicators viz. number of documents (NDs), citations and total linking strength (TLS). Normalized parameters are assumed to be better performance indicators in bibliometrics to represent the actual contribution of an author, organization or country. So normalized citations (NCs) have been calculated from the WOS data by writing Python code for it. Visualization maps have been created by VOS-viewer software to depict the result using normalized citations as weight.*

**Keywords:** Graphene, co-authors analysis, normalized citations, bibliometric analysis, electronic properties, VOS-viewer, bibliometrix.

## Introduction

In the middle of nineteenth century graphene was a hottopic of discussion. Graphene was believed not to be existing in a free state, as the two-dimensional crystals are thermodynamically unstable<sup>1,2</sup>. Such crystals require a three-dimensional support. In 2004 graphene, a 2D network of carbon atoms, was isolated from graphite using scotch tape method<sup>3</sup>. Geim & Novoselov were awarded Noble prize for their outstanding discovery and they termed it as a rising star<sup>4,5</sup>. P. R. Wallace was the first one to study the band structure of graphene and showed its semi-metallic nature to the world<sup>6</sup>. The sp<sup>2</sup> hybridized structure of graphene is a result of hybridization of one s and two p orbitals in a planar form. The  $\sigma$  bond formed between two in-plane carbon atoms have a lattice separation of 1.42 Å. The obands have filled shells and give graphene a robust structure. The p-orbitals are perpendicular to the planar structure and can form co-valent bonds with the neighbouring atoms. This leads to the formation of  $\pi$ -bands. The  $\pi$ - band are half filled as p-orbitals have one extra electron. The flexibility<sup>7</sup> in the structure of graphene is attributed to the out of plane vibrational modes which are responsible to its electronic properties. Graphene is

unique in the sense that it is flexible like a membrane and harder than steel. Graphene has unique set of electronic<sup>8</sup>, mechanical<sup>9</sup>, optical<sup>10</sup>, optoelectronic<sup>11</sup>, magnetic<sup>12</sup> properties and show IQHE<sup>13</sup> at ambient temperature. As a result, it has a wide application spectrum. Graphene finds applications in field effect transistors (FET), nano transistors<sup>14</sup>, organic light emitting diodes<sup>15</sup>, solid state battery<sup>16</sup>, superconductor<sup>17</sup>, E-textile<sup>18</sup>, paints and coatings<sup>19</sup>. Graphene finds applications in transparent conducting electrodes<sup>15</sup>, owing to its optical transmittance. It can bear high elastic strain and can be used for artificial skin generation and curing skin cancer<sup>20</sup>. Graphene also finds applications in wellness and health care industry<sup>21</sup>.

The versatile nature of graphene has created a gold rush among researchers to explore more about this wonder material, resulting in an exponential increase in the number of publications. It is impossible to explore such a huge literature manually. Bibliometrics, a powerful statistical data analysis technique, in association with analysis and visualization software can be utilized to achieve the objective. Bibliometricx<sup>22,23</sup> is a quantitative approach to study the academic literature in the form of articles, books or data bases

and to find the relationship among the published literature<sup>24</sup>. The term bibliometrics was first introduced by A. Pritchard<sup>25</sup> in 1969. Bibliometrics can be used to identify renowned authors, institutes and countries around the world. Bibliometrics enables to keep the record of the past research, helps in visualizing the present research trends and scope of the future studies on a particular topic or subtopic. It is flexible in nature and can be designed according to the requirement of the specific research topic. Bibliometric records can give new researchers an insight into the topic and provide opportunities to collaborate with renowned researchers. Coauthor-author analysis relates authors working on a specific topic. This is particularly beneficial for the researchers who are looking to collaboration with the authors having similar research interests. Researchers can refer the documents by renowned authors to get a deep insight into the subject. Coauthor analysis also finds the collaboration among the institutes and countries through coauthor-organization and coauthor-country analysis. This gives a golden opportunity to researchers to collaborate with renowned labs in different institutes and countries. Moreover, bibliometric studies also provide the information about the leading publishers and journals of a specific research field which can further be utilized for personal publications. In short bibliometric studies provide a background for the researchers in terms of collaboration with authors, labs, institutes and countries. Specialized software is required for bibliometric analysis and visualization. Bibliometrix R package has been used here for analysis and VOS-viewer<sup>26,27</sup> has been employed for creating visualization maps.

### Methodology

Web of science<sup>28-30</sup> (WOS), owned by Clarivate is the most reliable global citation database. WOS Core Collection consists of six indexing databases viz. Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (AHCI), Emerging Sources Citation Index (ESCI), Book Citation Index (BCI) and Conference Proceedings Citation Index (CPCI) dedicated to various disciplines. WOS consists of about 22,000 peer reviewed journals out of which 9,200 journals are from various science categories. It includes 254 subject areas, 2.4 billion cited references connecting research around the world and 97 billion records for journals, conferences, and books. Metadata on electronic properties of graphene was obtained by a search query in the title tab of WOS from 1<sup>st</sup> January 2004 to 24<sup>th</sup> March 2025 on the electronic properties of graphene and a total of 1873 articles were obtained.

### Results and Discussion

The metadata report, as obtained from bibliometrix software, on all indicators if found to be appropriate to proceed for the bibliometric analysis on electronic properties of graphene. The meta data report has been presented in Table-1. Data report status is excellent or good on all meta data parameters. The

missing percentage of keywords plus is 13.19% making it acceptable for the analysis. WOS core collection SCIE, CPCI-S and ESCI has published 1656, 156 and 61 articles respectively under various disciplines on the electronic properties of graphene. The distribution of Published literature based on various WOS categories on the electronic properties of graphene has been shown as a donut-chart in Figure-1. The published literature includes 1648 of articles, 149 proceeding papers, 42 review articles, 17 meeting abstracts and 15 book chapters. Segregation of published literature has been presented in Figure-2. Articles have a maximum contribution of 87% followed by proceeding papers (8%), review articles (2%) and books (1%) among the published literature on electronic properties of graphene. Publication statistics of various publication houses is shown in Figure-3. Elsevier has published maximum number of articles followed by Iop publishing limited and Royal Society of Chemistry on the electronic properties of graphene. The variation of number of documents as a function of publishing year on electronic properties of graphene is shown in Figure-4. A maximum number of 143 documents have been published in the year 2020. The same bar chart also represents the yearly cumulative citations obtained by the document as a function of year with the blue colour curve. Maximum citations have been fetched in the year 2021.

**Table-1:** Meta data report as obtained from Biblioshiny.

Meta data	Description	Missing Counts	Missing %	Status
AU	Author	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
WC	Science Categories	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
C1	Affiliation	7	0.39	Good
CR	Cited Reference	20	1.10	Good
RP	Corresponding Author	25	1.38	Good
AB	Abstract	56	3.09	Good
DI	DOI	76	4.19	Good
ID	Keywords Plus	239	13.19	Acceptable

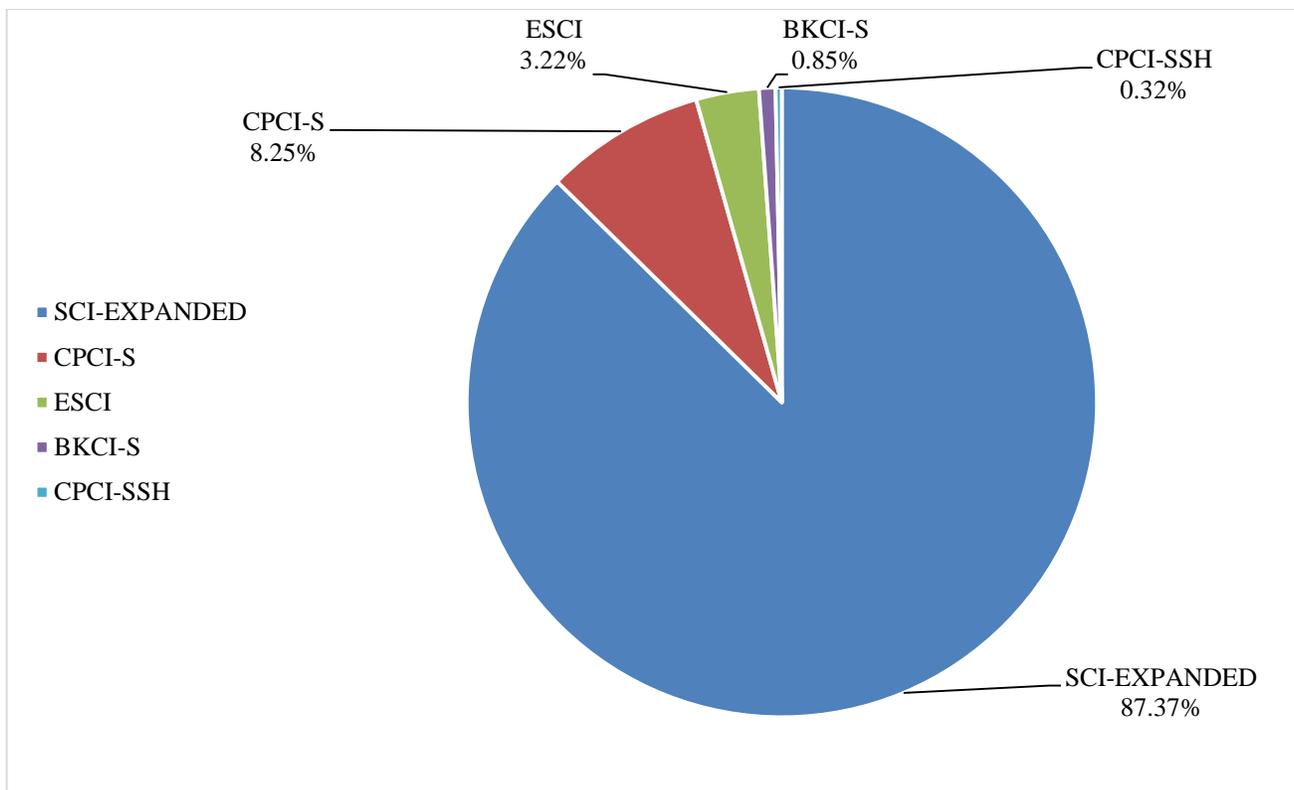


Figure-1: Contribution of articles from WOS core collection.

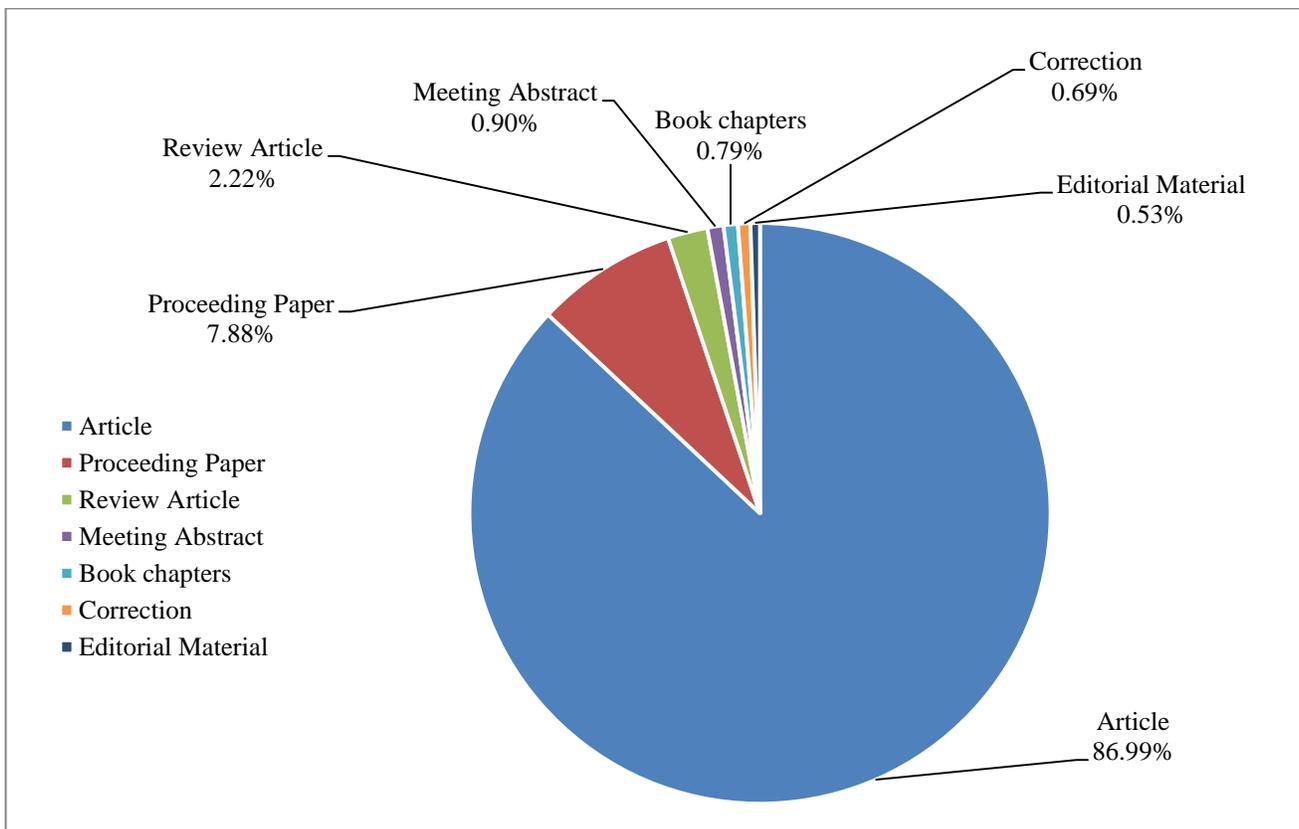
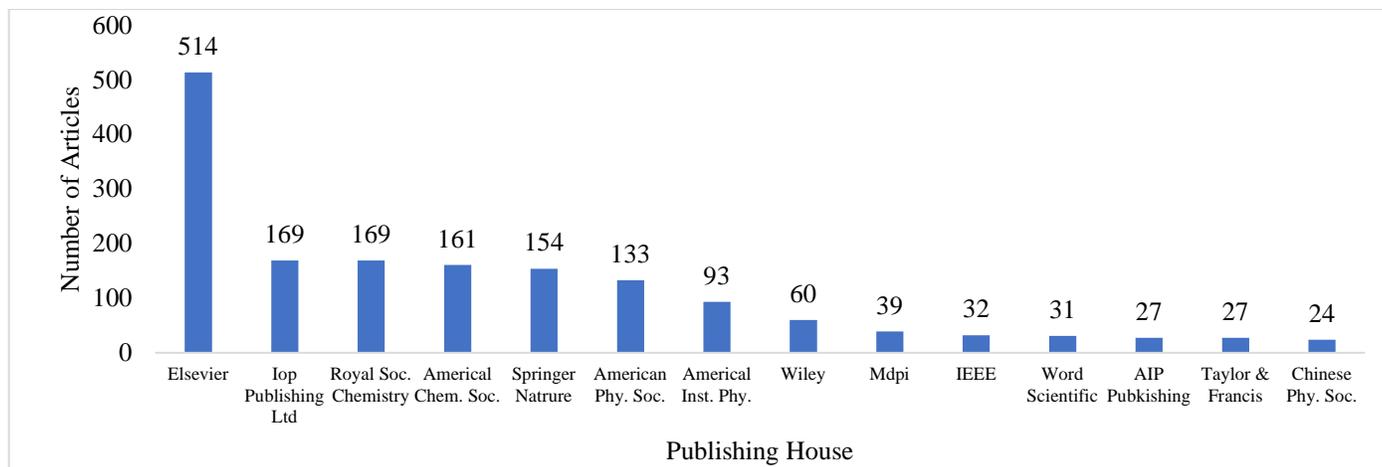
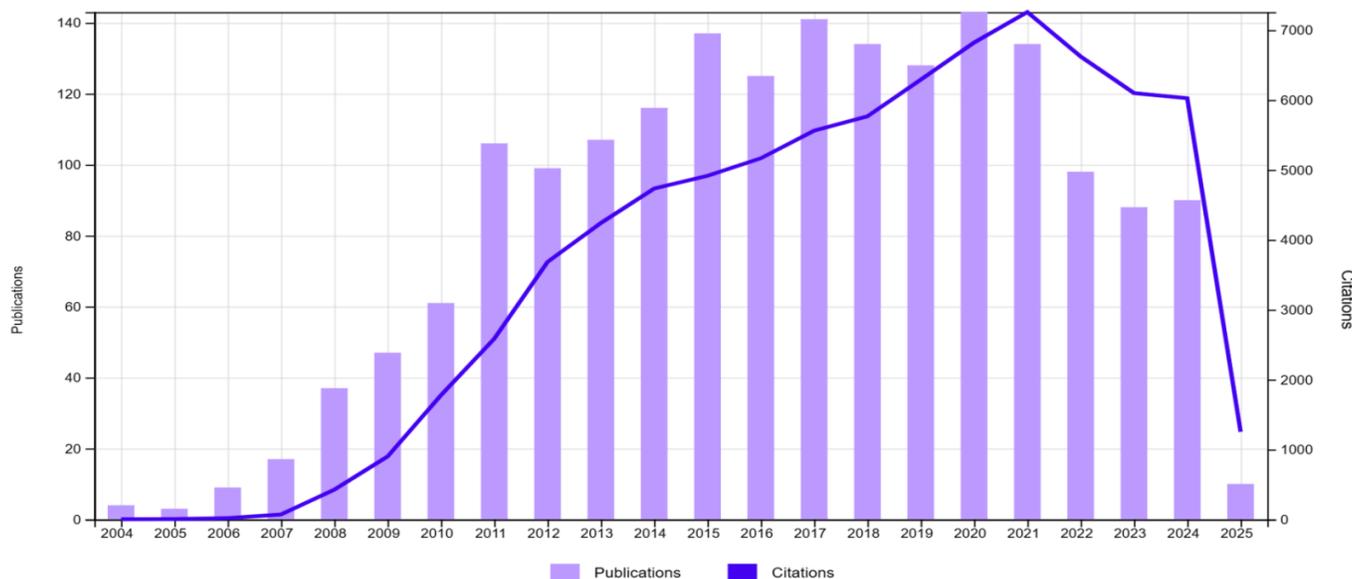


Figure-2: Publication statistics of literature on electronic properties of graphene.



**Figure-3:** Documents published by various publishers on electronic properties of graphene.



**Figure-4:** Year-wise variation of number of publications and cumulative citations received by the documents on electronic properties of graphene.

To identify the most renowned author, organization and country through the co-author analysis, various bibliometric indicators have been used. Bibliometric indicators used in the study are NDs, citations, NCs and TLS. Bibliometricians do not prefer the use of a single indicator for analyses, as each indicator provides a different information about the data<sup>31</sup>. Bibliometricians prefer the use of Normalized/ fractionalized<sup>32</sup> parameters instead of actual counts, if a research paper has a congregation of authors. The fractionalized parameters measures researcher’s contribution to the subject whereas the full count parameters measure the participation. Highest NDs represent the most productive author whereas the highest citations represent the most valuable work. Collaboration among the authors, organizations or countries is decided by TLS. NCs are the true representation of an author’s individual contribution to the work.

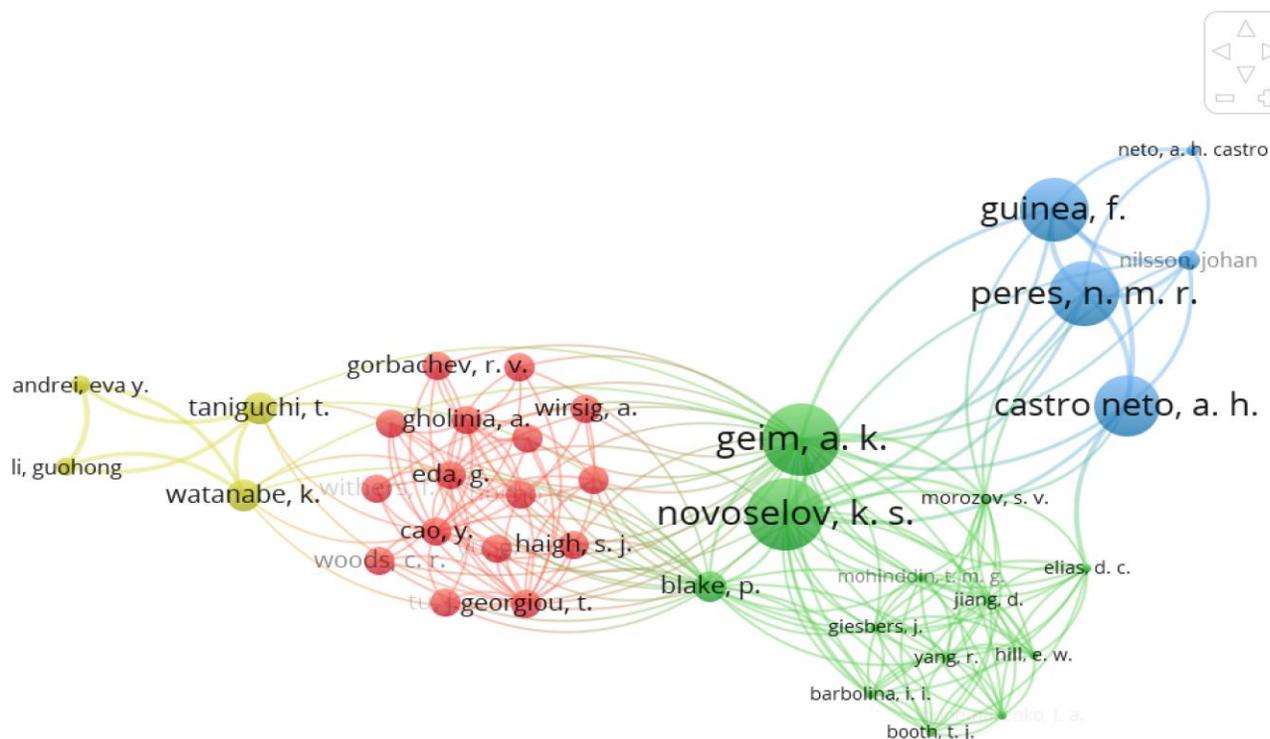
A total of 6106 authors has contributed to the research on the electronic properties of graphene. Coauthor-author analysis on the electronic properties of graphene has been represented in Table-2. In co-authorship analysis VOS-viewer calculates the total linking strength of the co-authored documents of the selected author with the other authors. The author with the highest total linking strength is selected as the top author in the hierarchy. Visualization maps using VOS-viewer can be generated considering weight as NDs, citations, TLS or NCs. In coauthor-author map each circle represents an author and the size of the circle represents the strength of the author. Four different coloured clusters showing the collaboration among the authors are visible in the coauthor-author analysis map in Figure-5. Hieu Nguyen N. has published maximum number of co-authored documents followed by Peres NMR. and Geim AK. Among the co-authored documents, Peres NMR has obtained

maximum citations followed by Geim AK and Novoselov KS. Documents authored by Geim AK and Novoselov KS have obtained maximum normalized citations. The statistics of the data reveals that NDs, TLS, citations as well as the NCs obtained by Geim AK and Novoselov KS are identical. This indicates that they have published all the documents in

collaboration with each other. Guinea F. and Peres NMR have the maximum linking strength, followed by Castro Nato AH and several others. Geim AK and Novoselov KS have the maximum NC revealing their valuable individual contribution to the research on the electronic properties of graphene.

**Table-2:** Co-author-Author Analysis.

Document		Citation		NC		TLS	
Hieu Nguyen N.	20	Peres N.M.R.	21903	Geim A. K.	55.4508	Guinea F.	5.00
Peres N.M.R.	7	Geim A. K.	21879	Novoselov K. S.	55.4508	Peres N.M.R.	5.00
Guinea F.	5	Novoselov K. S.	21879	Peres N.M.R.	48.1423	Castro Nato A. H.	4.00
Castro Nato A. H.	5	Guinea F.	21731	Guinea F.	46.8968	Geim A. K.	4.00
Miva R. H.	5	Castro Nato A. H.	21483	Castro Nato A. H.	43.5104	Novoselov K. S.	4.00
Sun Minglei	5	Bittner Alexander M.	2145	Watanabe, K.	16.8926	Sun Minglei	4.00
Yu, Jin	5	Burghard Marko	2154	Taniguchi, T.	16.8926	Yu, Jin	4.00
Geim A. K.	4	Gomez Navarro Cristena	2145	Blake, P.	15.6911	Fazzio A.	3.00
Novoselov K. S.	4	Kern Klaus	2145	Yu, G. L.	14.4367	Miva R. H.	3.00
Fazzio A.	4	Mews Elf	2145	Woods, C. R.	14.4367	Grueneis A.	3.00



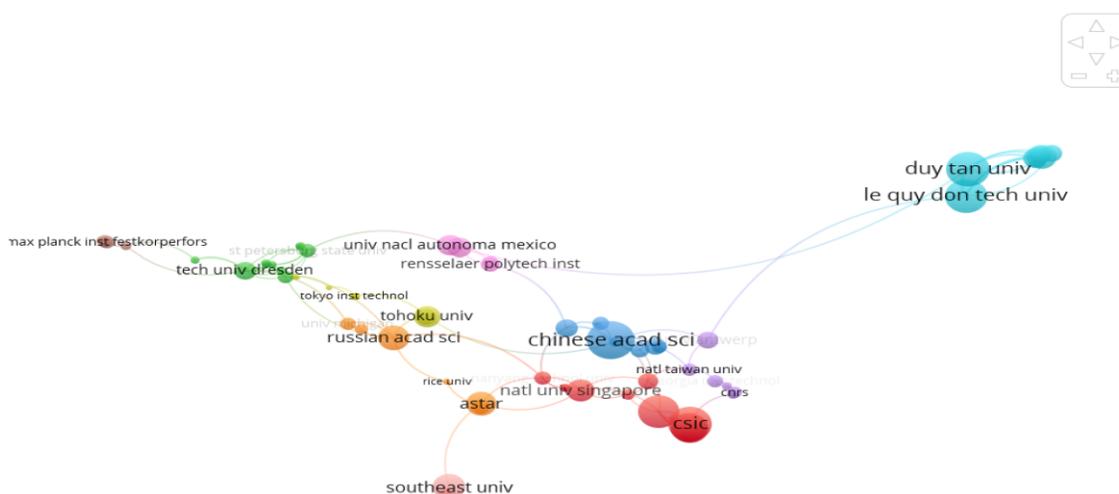
**Figure-5:** Coauthor-author map using NCs as weight on electronic properties of graphene.

A total of 1652 organizations have been involved in the research on the electronic properties of graphene. Coauthor-organization analysis for the first ten organizations contributing to the electronic properties of graphene has been represented in Table 3 in a hierarchical order. In co-authorship analysis VOS-viewer calculates the total linking strength of the co-authored documents of the selected organization with the other organizations. The organization with the highest total linking strength is selected at the top in hierarchy. Coauthor-organization analysis has been performed based on four bibliometric indicators as shown in the table. Chinese Academy of Science has published a maximum of 48 documents in collaboration with other organizations followed by National

Cheng Kung University and Islamic Azad University. The NCs obtained by organizations follow an entirely different hierarchy. CSIC has topped the list by obtaining maximum citations but secures third place in terms of NCs. Chinese Academy of science has obtained a smaller number of citations and secures 9<sup>th</sup> place in the list but leads in terms of NCs. Duy Tan University has collaborated with other organizations with the highest TLS of 32.00 followed by Le Quy Don Technical University and National Cheng Kung University. Coauthor-organization visualization map based on NCs has been presented in figure 6 and can be mapped with fifth and sixth column of Table-3.

**Table-3:** Co-author-Organization Analysis.

Document		Citation		NC		TLS	
Chinese Acad. Sci.	48	CSIC	22387	Chinese Acad. Sci.	65.7365	Duy Tan Univ.	32.00
Natl. Cheng Kung Univ.	43	Univ Minho	21933	Duy Tan Univ.	58.6239	Le Quy Don Tech. Univ.	30.00
Islamic Azad Univ.	41	Univ. Manchester	21884	CSIC	57.7171	Natl. Cheng Kung Univ.	24.00
Duy Tan Univ.	33	Boston Univ.	21747	le Quy don tech univ.	55.9582	Chinese Acad. Sci.	19.00
Le Quy Don Tech. Univ.	31	Max Plank Inst. Festkorperforsh	2791	Univ. Manchester	55.6889	Ton Duc Thang Univ.	17.00
Russian Acad. Sci	26	Ecole Polytech Fed Lausanne	2512	Univ. Minho	48.1967	CSIC	15.00
Univ. Sci. & Tech. China	21	Univ. Siegen	2098	Boston Univ.	47.0995	Henan Normal Univ.	13.00
Harbin Inst. Tech.	20	Univ Illinois	2077	Southeast Univ.	41.7512	Don State Tech Univ.	12.00
Changsha Univ. Sci. & Tech.	20	Chinese Acad. Sci.	1918	Russian Acad. Sci.	39.001	Xi an Jiao Tang Univ.	12.00
Univ. Antwerp	19	Univ. of Singapore	1810	Aster	37.2445	Dong Thap Univ.	12.00



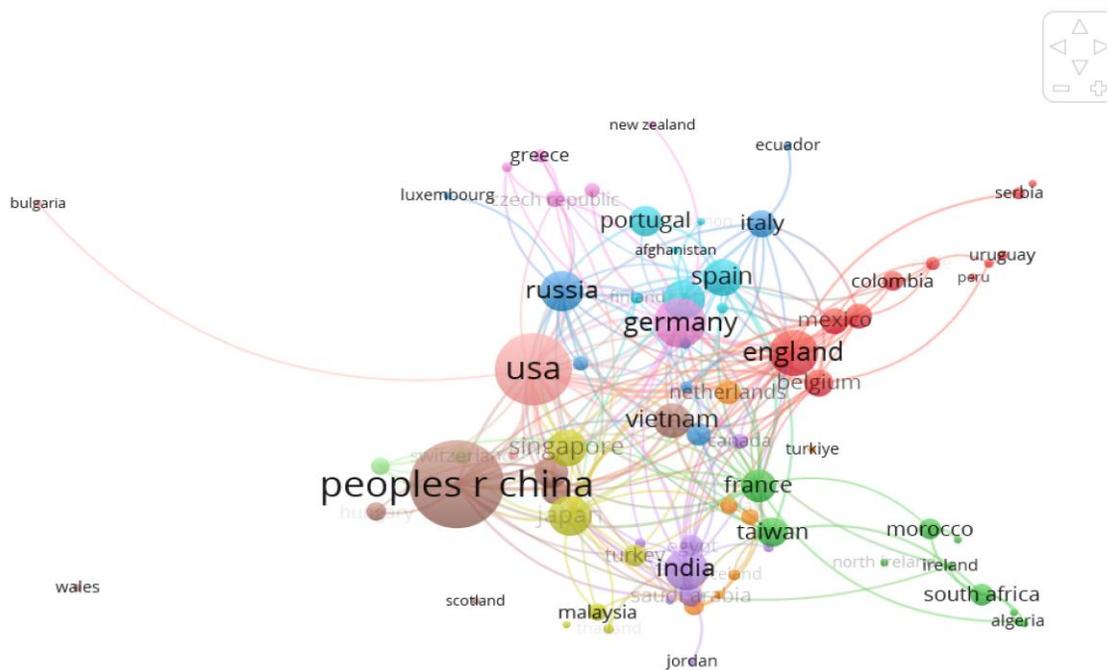
**Figure-6:** Coauthor-organization map using NCs as weight on electronic properties of graphene.

A total of 85 countries has been involved in the research on the electronic properties of graphene. The hierarchy of coauthor-country analysis for the first ten countries has been represented in Table 4. In coauthor-country analysis VOS-viewer calculates the TLS of the co-authored documents of the selected country with the other countries and the country with the highest number of coauthored documents is considered as the leading country. PRC has published maximum number of documents on the electronic properties of graphene followed by USA and India.

USA has obtained maximum number of citations followed by Spain and England. Though PRC has published maximum number of articles but in terms of citations it falls down to 5<sup>th</sup> place. NCs represent an entirely different statistics with PRC securing the first place followed by USA and Germany. USA has the maximum collaborating strength. PRC and Germany stand second and third in terms of TLS. Choosing NCs as the bibliometric indicator the coauthor-country visualization map has been shown in figure-7.

**Table-4:** Coauthor-Country Analysis.

Document		Citation		NC		TLS	
PRC	554	USA	35603	PRC	560.3885	USA	147.00
USA	236	Spain	24946	USA	361.6228	PRC	111.00
India	153	England	23331	Germany	158.4394	Germany	69.00
Iran	125	Portugal	22129	England	137.9027	Russis	49.00
Germany	104	PRC	14007	India	113.7265	England	46.00
Russia	100	Germany	7580	Russia	107.4068	France	44.00
Japan	86	Japan	5167	Japan	103.6573	Japan	39.00
Taiwan	77	Russia	4294	Iran	101.6028	Vietnam	36.00
France	63	Singapore	3038	Spain	89.5108	Spain	36.00
Brazil	62	Switzerland	2912	Singapore	84.7519	India	36.00



**Figure-7:** Coauthor-country map using NCs as weight on electronic properties of graphene.

## Conclusion

According to biblioshiny, the metadata fulfils the desired requirements on all bibliometric indicators. SCI-EXPANDED has contributed 88% of the total published documents on the electronic properties of graphene. Out of the published literature 87% contribution is from the journal articles. Elsevier publishing house has published maximum number of documents on electronic properties of graphene followed by Iop Science Limited and Royal Society of Chemistry. A maximum of 143 documents has been published on the electronic properties of graphene in the year 2020. Documents on electronic properties have obtained maximum cumulative citations in the year 2021. Coauthor-author analysis reveals that among the ensemble of authors, the most renowned authors are Geim A. K. and Novoselov K. S. having maximum number of NCs. Most valuable contribution is from Chinese Academy of Science based on coauthor-organization analysis. Duy Tan University and CSIC secure second and third place respectively in terms of collaboration with other organizations. People Republic of China has co-authored maximum number of documents with other countries of the word followed by United States of America and Germany. Co-author analysis reveals that more NDs and TLS lead to greater number of citations and NCs.

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