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A Bibliometric Study on Twisted Graphene

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Abstract: *Graphene is a flat monolayer of carbon atoms tightly packed into a two-dimensional honeycomb lattice and has completely conjugated sp^2 hybridized planner structure. Its peculiar structure makes it useful for numerous applications. Graphene sandwich and twisted graphene are the most recent and tempting forms of graphene. Twist in graphene layers can introduce several angle dependent properties. Twisting graphene layer by magic angle (1.1^0) and applying electric field can convert graphene from an insulator to a conductor and then to a superconductor, which can conduct electricity flawlessly. Looking into the potential for future applications of twisted graphene a bibliometric analysis has been undertaken on this topic. Bibliometrics is the most appropriate tool to keep the track on present and past research trends. In this paper, Web of science, the most authentic data base has been utilized to analyse the research trends on twisted graphene since its discovery by Geim and coworkers. Data has been obtained from theyear 2004 to 2020 and has been analysed by the VOS viewer tool. Publishing trends have been analyzed on the bases of collaborating authors, organizations, countries, citations, keywords and the leading journals publishing graphene research.*

Keywords: Bibliometric analysis, graphene, twisted graphene, Web of Science, VOS viewer tool

I. INTRODUCTION

Graphene research started in 2004 and has shown a tremendous growth since then. Peculiarity of its structure has made it of great use ranging fromsuper capacitors[1], gas detectors[2], [3]biomedical applications[4], [5], water purification[6] to superconductors[7], [8]. A curious human mind never stops and this zeal gave invention of a new form of graphene called twisted graphene[9], [10]. Researchers at the Massachusetts Institute of Technology (MIT) stacked, two sheets of graphene(one atom thick), twisted them and applied electric field. This process converted graphene to a super conductor. The material so formed did not show hinderance to the path of current through it. The study of this branch of graphene is named as twistronics. Twisted graphene has the potential to revolutionize whole electronic industry, which requires cumbersome procedures to fabricate electronic components. Group of scientists from Columbia University and MIT have built devices such as Josephson junction and a transistor. This transistor is able to control the movement of single electron. If it is possible to fabricate such energy saving devices commercially, it is going to reduce the energy consumption in electronic devices [11], [12].

Bibliometrics was Introduced to the world by Pritchard A[13]. Bibliometric 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 related to science, technology or humanities. These studies can then serve as the bases for new researchers on that area and specifically on the topic. Bibliometricsrelates authors and co authors working on a specific topic/area. It also gives the information regarding the country and institute these authors belong to. Moreover, one can find out the publication sources who have the thrust to publish research in specific area. Hence the information about a topic/sub-topic and the scope of future studies become handy with bibliometrics.

Web of Science (WOS) was known as the Science citation index in past.WOS is the most powerful research engine and publisher-independent global citation database. It provides about 1.9 billion cited references from over 171 million records. **Science Citation Index Expanded (SCIE) s**earch across over 9,200 of the world's most impactful journals across 178 scientific disciplines. It provides 1.18 billion cited references date back from 1900 to present. Scopus is the largest abstract and citation database of peer-reviewed literature. It provides a comprehensive overview of research conducted in science and technology, medicine, social sciences and humanities.

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Keeping in mind the potential for applications of exotic graphene, an effort has been made to undertake the bibliometric analysis on twisted graphene fromthe years 2004 to 2020.VOSviewer[14] software has been used as a tool for the visualization scientific maps.Data obtained from Web of science and Scopus databases on different subtopics of graphene has been compared. Detailed study is focused on twisted graphene.

II. Material and Methods

WOS and Scopus searches were done directly from the respective data base. Searches of WOS and Scopus were performed by putting different variants of graphene such as graphene, graphene oxide and graphite in the title field. In the topic field 'twisted graphene' was entered. Boolean operators were used in upper case for different variants of graphene. 142 result were obtained for this query.

III. Results and Discussion

Year-wise publishing trend on graphene has been shown from its discovery year, 2004 till March 2020 in figure 1. There is an increase in the number of publications every year till 2019. Less publications in the year 2020 may be due to either the pandemic effect or the fact that the was collected in March 2020.

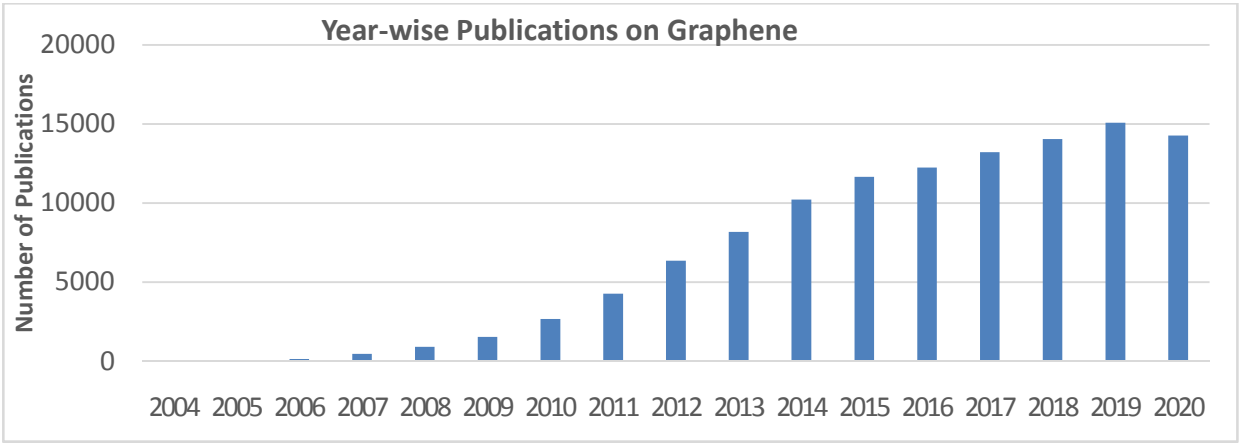

Figure 1: Year-wise publishing trend on graphene from 2004 to 2020.

Application potential of graphene has been depicted from WOS and Scopus data bases respectively in figure 2. Both the data bases have published consistent number of papers. Publications by Scopus data base are higher in number in comparison to the ones published by WOS for all the applications of graphene. Graphene has been known for its excellent mechanical properties. Number of publications for mechanical properties of graphene has not been included in the graph as it was very high in number and was obscuring other results. WOS and Scopus published 9849 and 9892 papers respectively on mechanical properties of graphene in the selected year range. Optical[15], electrical[16], structural[17] and mechanical properties[18] of graphene have been studied from the very beginning and huge literature is available on it. Twisted graphene, graphene sandwich[19], [20] and superconducting[21] graphene being relatively recent topics are of potential importance for scientists and researchers.

3.1 VOSviewer Analysis

In all the maps the size of the circle is in the hierarchal order of the depicted parameter. All curved lines are showing the connection among the chosen parameter. Maps have been created to represent the data based on the chosen numerical values of the parameters in the software and only connected parameters are shown in the maps. Clusters formed are shown by different colors in the map.

Author-coauthor collaboration: Author-coauthor collaboration map generated by software is shown in figure 3. Minimum number of documents of an author and number of citations of an author were set to 3 and 43 respectively. Out of 594 authors 21 meet the requirement and 14 fit in the selected search. Three clusters were formed by the selected data having 9, 3 and 2 items respectively.

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Author-organization collaboration: This map (Figure 4) summarizes the results of the co-authored documents of a particular organization.

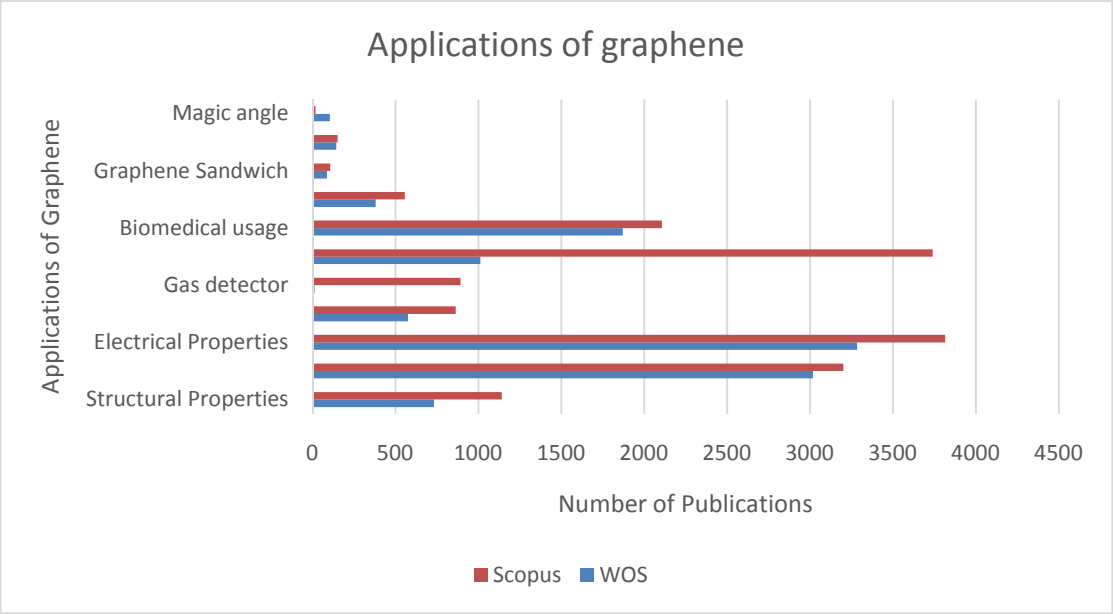

Figure 2: Number of publications on applications of graphene as obtained from WOS and Scopus databases respectively.

Minimum number of documents of an organization and number of citations were set to 1 and 47 respectively. Out of 208 organizations 40 meet the requirement and 12 fit in the selected search. Four clusters were formed by the selected data having 5, 3, 3 and 2 items respectively.

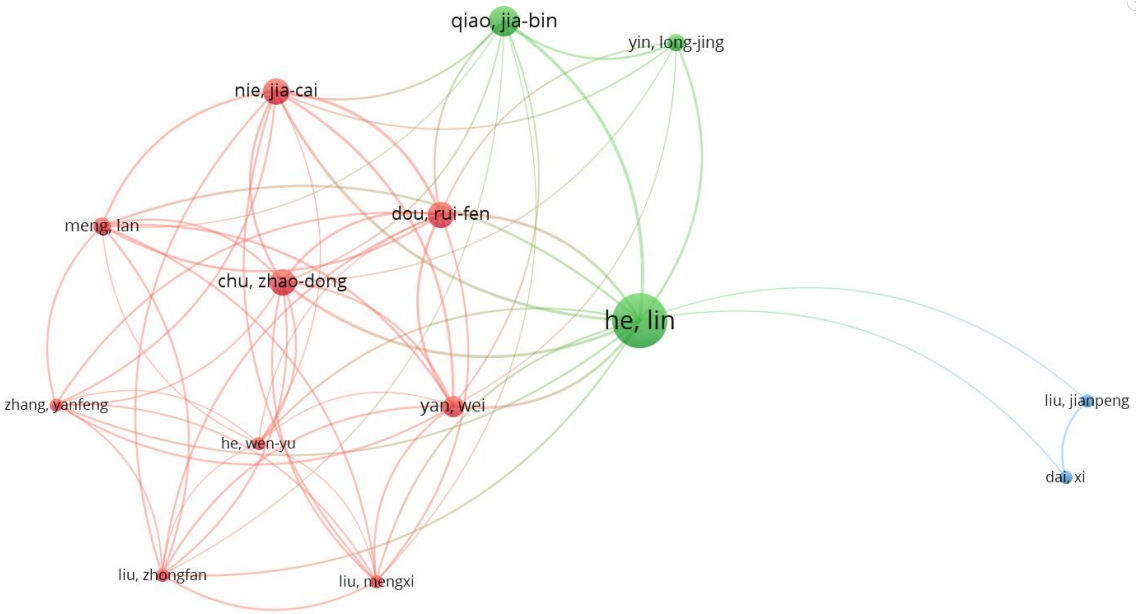

Figure 3: Scientific map representing author-co author collaboration having three clusters.

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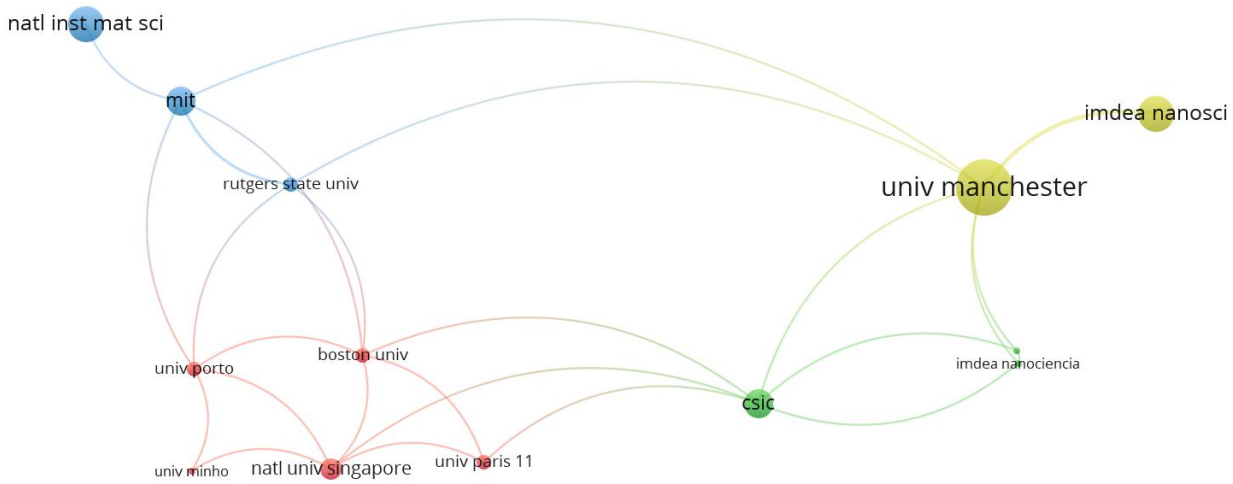

Figure 4: Scientific map representing co-author-organization collaboration having three clusters.

Co-authorship-country analysis: Co-author-Country relationship map has been shown in figure 5. In the analysis minimum number of documents of a country and minimum number of citations of a country was chosen to be one respectively. This search fetches 35 results and seven cluster were identified.

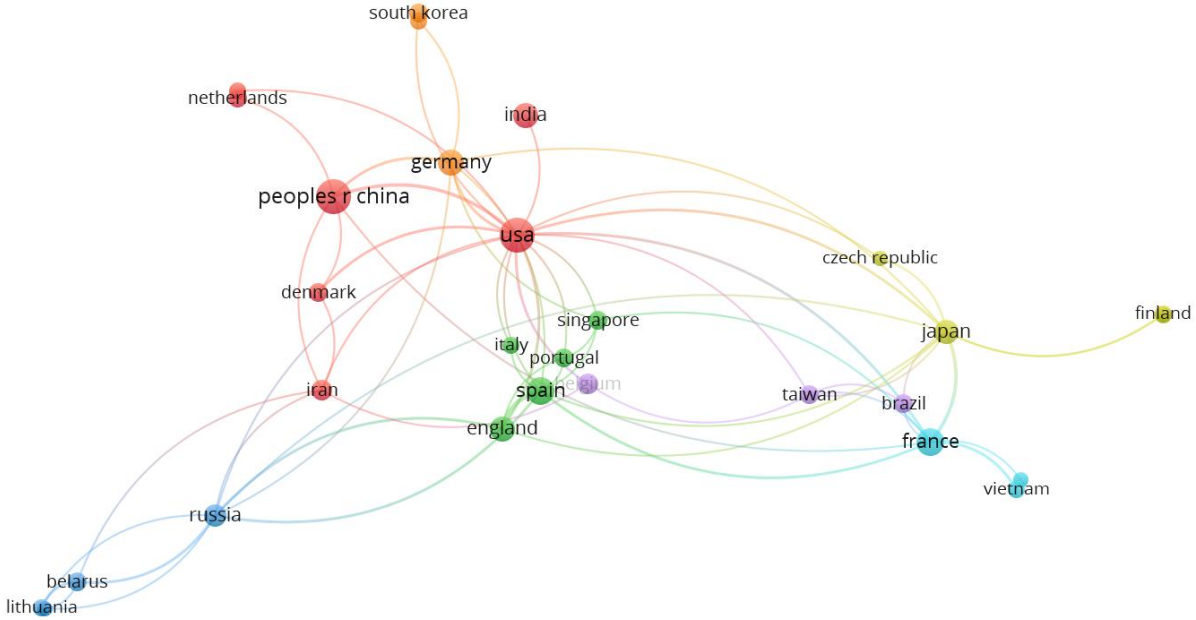

Figure 5: Scientific map representing co-author-organization collaboration having three clusters.

3.2 Co-Occurrence Keyword Analysis

Keyword's analysis is of utmost importance as it focuses on the core content of a publication. Hence co-occurrence analysis was done for keywords using the full counting method. There are three options for keyword analysis. Co-occurrence can be related to keywords, author keywords and all keywords. As all three were giving more or less the similar keywords, so only one map has been taken into consideration. Hierarchical order of the keywords used is graphene, twisted graphene, thermal conductivity, magic angle, twisted bilayer graphene, twisted multilayer graphene, X-ray photoemission spectroscopy, superconductivity, scanning electron microscopy, moire pattern, superlattices and spin efficiency Minimum number of co-occurrence of a keyword was set to 5 and total 21 results were fetched. For each keyword, the total strength of the co-occurrence links with other keywords was calculated and keywords with the greatest total link strength were selected. Total four clusters were found and the map is shown in figure 6.

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Citation -documents analysis: Minimum number of citations of a document were set to 5. Out of 142 documents 106 meet the requirement. he, lin was found to have 13 documents having 551 citations and a link strength of 228.

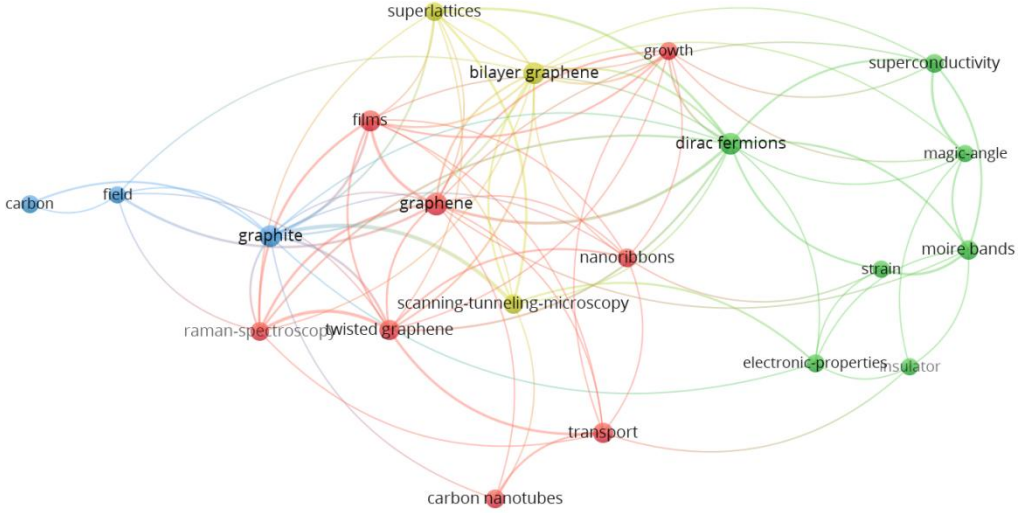

Figure 6: Scientific map representing co-occurrence of keywords having four clusters.

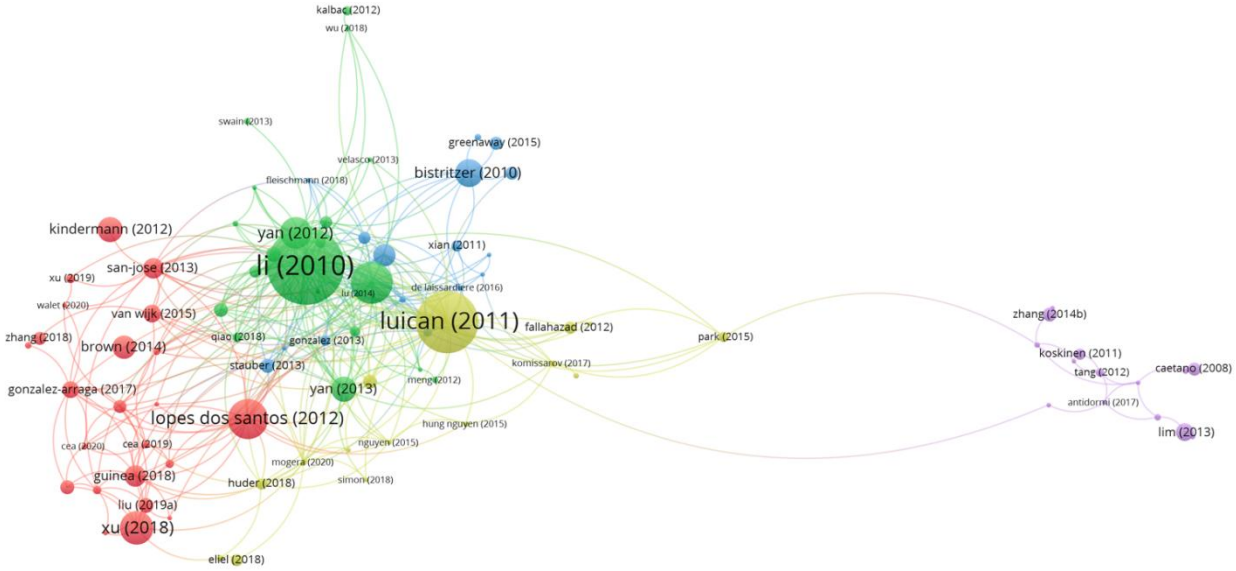

Figure 7: Scientific map representing Citation -documents analysis.

Citation -source analysis: This analysis gives he relatedness of number of citation of a document published in a journal. Minimum number of documents of a source and minimum citations of a document were set to one and two respectively. Six cluster were forms having 5, 5, 3, 3, 2 and 1 items. Out of 53 results, 21 one meet the requirement. This map is shown in figure 8.

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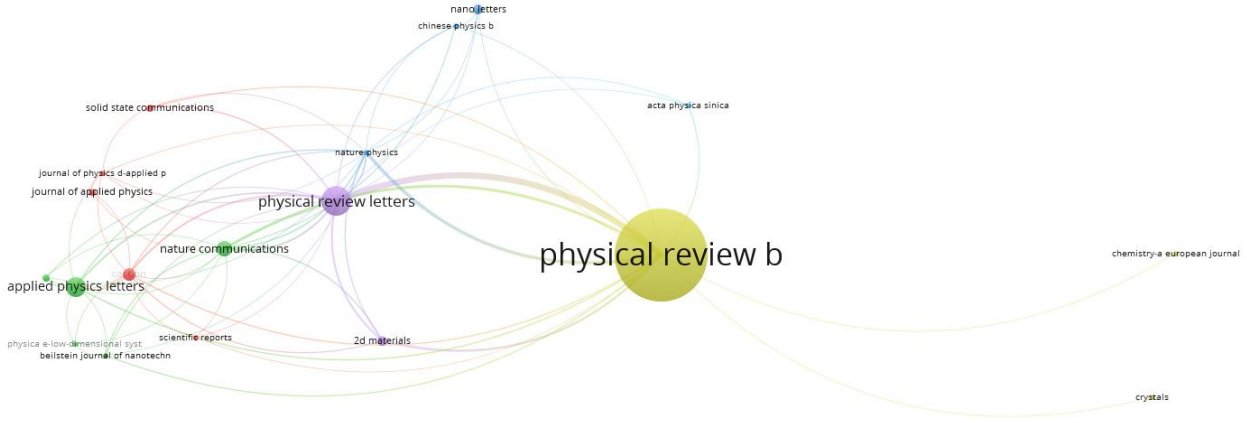

Figure 8: Scientific map representing Citation - source analysis.

IV. Conclusion

1. Co-author – Author: he lin has 13 documents with 551 citation and link strength of 52.
2. Co-author-organization: University of Manchester tops the list with 705 citations with 8 such documents. Beijing Normal university is second with 13 documents and 551 citations.
3. Co-author-Country: USA is the country with maximum number of documents (37) having 2183 citations at a link strength of 312. Spain and France secure second and third place in this category.
4. Co-occurrence-keywords: Graphene, twisted graphene, thermal conductivity, bilayer twisted graphene are the keywords used in hierarchical order.
5. Citation-Documents: li has the maximum (597) citations with 45 links.
6. Citation-Author: he lin has maximum documents (13) with 551 citations and 228 link strength.
7. Citation -Organization: Beijing Normal University has maximum citations (551) for 13 documents with a link strength of 126.
8. Citation- Country: USA is the country with maximum citations (2183) for 37 documents with a link strength of 312.
9. Citation-Source: Physical Review B is the leading Journal in terms of publishing papers on twisted graphene and has published 40 papers with 1264 citations having a link strength of 160. Physical Review Letters and Nature Physics are second and third in this hierarchy.

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