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Scientometric Analysis of Graphene

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ABSTRACT

Purpose

The unique properties of graphene and its extensive applications has turned it an emerging area of research. Therefore, this study is an attempt to analyse the research output trends in graphene during the period 2010 – 2012 for the publications indexed by Web of Science.

Methodology

The study maps the parameters of output, journal productivity and the impact strength of publications. The Institute for Scientific Information Web of Science database core collection was used to retrieve the data. Quantitative analysis of quantity and quality of research out-put was undertaken to attain the objectives.

Findings

The analysis revealed a steep growth in the production of research publications. Further, a total of 430 journals, publishing research on graphene, were traced, with 'PHYSICAL REVIEW B' being the top productive journal having 1694 (11%) publications. From citation analysis 'ACS NANO' was found to be the journal scoring highest number of citations and the individual publication published in year 2010 marked the highest (7048) citation impact strength with 881 as the average citation rate per year.

Value

The present study would aid to unravel the emergence and rise of research on graphene that would be beneficial for researchers and information scientists.

KEYWORDS

Carbon Allotrope, Graphene, Nano-tubes, Fullerenes, Scientometrics, Bibliometrics.

INTRODUCTION

The alarming rate of increase in literature has lead to the development of various studies pertaining to the literature. Among all these studies metrics based study is mostly in vogue currently and among the metric studies scientometrics is the popularly employed one. Scientometrics is used to study all aspects of science and technology literature. Scientometrics was first introduced by Nalimov and Mulchenkov in 1969 **(Brindha and Murugesapandian, 2016)** for studying growth, structure, productivity and relationships in science **(Correia et al., 2017)**. The scientometrics, as defined by **Nalimov and Mulchenkov (1971),** include "the quantitative methods of the research on the development of science as an informational process". The main studies Scientometrics aid in pertain to mapping of

scientific fields, citation analysis, measuring and evaluating research quality and impact and the use of indicators in research policy and management **(Mingers and Leydesdorff, 2015).** It involves application of quantitative methods for measuring scientific and technological progress and helps to gauge the productivity of a subject and of researchers in a field so as to portray the growth and development of that particular field of knowledge **(Araujo and Oliveira, 2015)**. The subjects of study in scientometrics include- scientific Publications, academic journals, authors/researchers, scientific institutions and regional aspects of science. Therefore, based on some of these scientometric indicators this study analyses the research trends in graphene, a carbon allotrope, one of the hottest topics currently being researched and explored the world over.

Graphene, the latest thinnest (one-atom thick), strongest, two dimensional allotrope of Carbon is the basic building block for other graphitic materials **(Geim and Novoselov, 2007)** including carbon nano-tubes and large fullerenes- two other allotropes of carbon. Thus, the properties these exhibit basically originate from the graphene sheets **(Taghioskoui, 2009)**. Graphite and Diamond form the two natural allotropes of carbon and since 1985 scientists began to discover synthetic allotropes of carbon also **(Hirsch, 2010).** Until recently, scientists were able to extract three dimensional (diamond, graphite), one dimensional (nanotubes) and zero dimensional (fullerene) allotropes of carbon only **(Builova and Osipov, 2011)** and planar graphene was considered unstable **(Odegard et al., 2002)** but Geim and Novoselov in 2004 were successful to isolate this two dimensional carbon allotrope too **(Lv et al., 2011)** by mechanically exfoliating graphite **(Lee et al., 2016)** and received Nobel Prize in Physics in 2010 for this ground breaking experiment **(Nobelprize.org, 2018)**. This material is considered as more solid and stronger than steel and better conductor than copper **(Larousserie, 2013).** The properties of graphene are making its applications possible in almost all fields like materials science, biotechnology, chemistry, physics **(Mao et al., 2013)** and medicine **(Bernabo et al, 2018).** Thus, because of its applications and unusual mechanical, thermal and electronic properties, it has received a tremendous research interest, since its development, from researchers of varied disciplines **(Lv et al., 2011).** Because of this out-break of intense research interest **Woodford (2018)** opines that 21st century may become the age of graphene. Therefore, measuring the research output trends of such a promising and most researched material would be beneficial and invaluable too.

LITERATURE REVIEW

The element carbon has been a topic of great interest among researchers since decades. Research on various carbon materials and allotropes, particularly the newly discovered graphene allotrope, seems explosive. Because of its some unusual properties graphene has attracted a lot of interest from researchers around the world and lot of literature published and

new and novel findings reported. The research on graphene is supposed to garner great benefits in future. Therefore analysing the development of its production would be invaluable. **Datta and Ruth (2013)** conducted a scientometric study on carbon nanotube research in India from 1999 – 2012 using data from web of science and found increasing trends in its research since 2008 with the maximum increase in 2011 and the prominence of collaboration and team research and found USA as the most preferred collaborating country. Similarly, **Melanez et al. (2013)** analyzed the scientific publications on carbon based nano materials using Web of Sciences analytical tool and found an alarming increase in the research publications in the fields of graphene and nano-tubes than those of nano-technology publications. Besides, they also traced an increased performance of publications in graphene and nanotubes than those of publications in Fullerenes. **Builova and Osipov (2011)** conducted a study, to analyse the thematic scope of publications on graphene research using publications from the peer reviewed journal of 'The Physics of Nano-objects and Nanotechnologies' published by the All Union Institute for Scientific and Technical Information of the Russian Academy of Sciences (VINITI RAS), in the period between 2010 and the first half of 2011, in which they note that publications on fullerene started expanding after a gap of 26 years after their extraction, after 10 years for nano-tubes and only after 2 to 3 years for the graphene after its extraction i.e., only from 2006 the publication out- put is remarkable when it was extracted in 2004. They further concluded that most of the research on graphene revolves around their properties. **Lv et al. (2011)** evaluated global scientific production and developing trend of graphene for the time period 1991 - 2010 by applying bibliometrics and knowledge visualization technology on the data collected from Thomson Reuters Science Citation Index database, Conference Proceeding Citation Index database and Derwent Innovation Index and traced an exponential growth in the annual number of publications, particularly from the year 2005, with 7523 articles distributed in 75 subject categories, among which physical science tops the list, published in 382 journals with Physics Review B journal the most productive one.

Randviir et al. (2014), in their study, report that only in year 2013 the number of publications produced per day on graphene were more than 40. Similarly, **Zou et al. (2018)** has studied the research trends in graphene throughout the world using data from Chemical Abstracts Services (CAS) and found that research and development in graphene is at a rapid growth with continuous expansion of research topics and applications with China, South Korea and USA the largest producers in research. Accordingly, **Barth and Marx (n.d.)** analysed literature on graphene from CAplus database of Chemical Abstracts Service, the INSPEC database of the Institute of Electrical and Electronics Engineers and the Web of Science (WoS) of Thomson Reuters, and mapped research trends with respect to the most productive authors, research organizations, countries of authors, and the

leading journals. Besides they also analysed the citation impact of the publications and revealed much greater citation scores for the graphene publications than those of fullerenes or nanotubes. **Bernabo et al. (2018)** carried out a scientometric analysis of scientific literature, indexed in Web of Science, for the use of graphene and graphene-based materials in medicine and concluded that in the last 15 years more than 1200 issues have been produced, with an *H*-index of 67 cited 2647 times. Despite the massive applications of graphene in biomedical and bio-engineering fields, their study revealed least research activities in these areas. The publications analysed were mostly concerned with materials science, science and technology, chemistry, physics and engineering.

The patent production on graphene is also having a rapid boom. **Shapira et al. (2012)** retrieved 911 patents on graphene from Thomsons Derwent Index for time period 2000 – 2010 while **Dhand et al. (2013)** retrieved 2306 graphene patents from the same index for time period 2000 – 2012, that illustrates a surge of almost 1395 patents within a period of 2 years (2010 - 2012) only.

Thus, from literature survey, a spectacular growth in research literature, mostly pertaining to the properties and applications of graphene, has been revealed since its extraction, in almost all fields.

PROBLEM

The promising application and potential of graphene in diverse fields has lead to its research boom. Researchers from wide range of fields are in the progress of making further developments in this area, thus adding to its literature output. This vast expansion of literature demands measurement of its dimensions and other features so as to provide some sort of prospectus for strategic planning of future research in this area. Therefore, present study is such an attempt to analyse the research out-put published on Graphene as indexed by the Web of Science database.

SCOPE

The bibliographic and citation data from the research papers, published during time-span of 2010 – 2012, on carbon allotrope- graphene have been analysed. The data for the study have been collected from the bibliographic database- Web of Science (WoS).

OBJECTIVES

1. To analyse the global publication growth trend in the graphene research.
2. To identify the prolific journals in the area.
3. To identify high impact publications.

METHODOLOGY

To identify trends in graphene research, the Institute for Scientific Information Web of Science database core collection was used to retrieve the data. The data was collected on 05 - 10 – 2018. A total of 16183 papers were harvested. The data retrieval and analysis comprised following steps:

1. *Retrieval Strategy*

   The key-term graphene was used for the search process. In the advanced search mode interface of Web of Science the query was put as- TS="GRAPHENE" in the search box, where 'TS' stands for topic. From the same interface time-period was set for 2010 – 2018, document type was limited to articles only and language selected was English. The search was run and the results set of 135475 items were retrieved and the results displayed included all the articles published from 2010 – 2018

2. *Filtration*

   The retrieved results were then refined for the publication years of 2010, 2011 and 2012, individually. Accordingly, citation report for each publication year was generated. The results besides giving all the bibliographic details of the items furnished the year-wise citations for all the items, individually, for the publications of a particular year (hosted by the database). Besides, it also gives total citations calculated for all the years and also, average citations per year separately for all the items in a results set.

3. *Data extraction*

   The results retrieved after generating citation reports, individually for each year, were useful data for the study. For exporting these datasets the records were downloaded in the sets of 500 items at a time, the maximum record limit set per download for the feature in the database, till all the items were collected and saved to the excel file, using the 'export data' option of the database. The procedure was followed for all the three publication years i.e. 2010, 2011 and 2012, respectively. The harvested data saved to excel file was then subjected to further analysis and interpretation in light of the said objectives.

RESULTS AND DISCUSSION

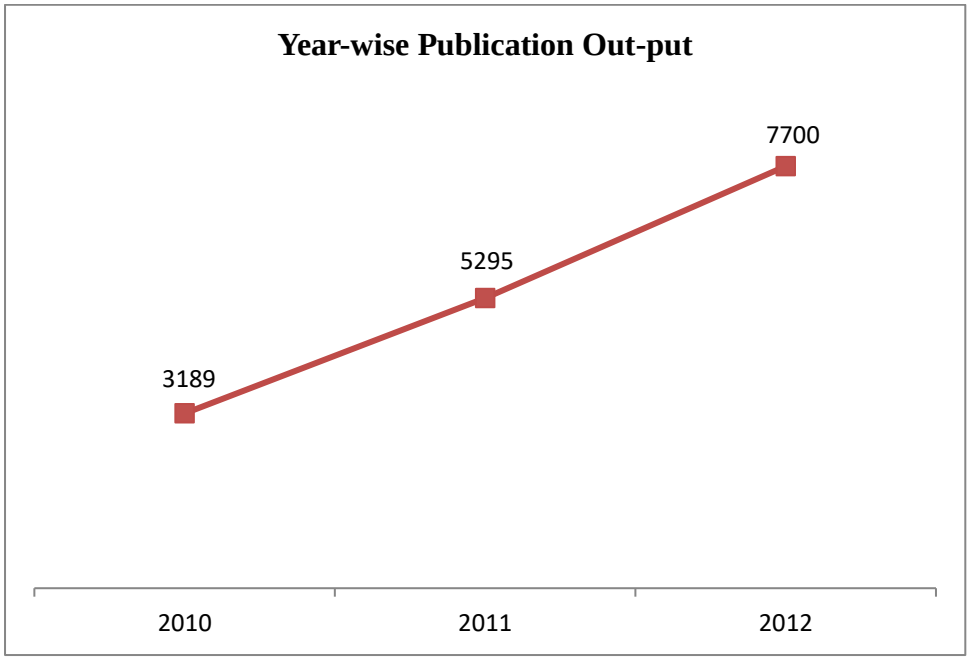
The data collected was analysed on the parameters of production, leading journals and paper citations as –

1. Year-wise Publication Out-put

The publication output of graphene research from 2010 – 2012 is given in the graph 1.

There are total of 16213 papers indexed in the Web of Science for the said time period. Out of 16213 publications 3189 papers are published in 2010, 5295 in 2011 and 7700 in 2012 i.e., year 2010 to 2011 and 2011 to 2012 mark the growth rate of 68% and 45%, respectively. This is in consonance

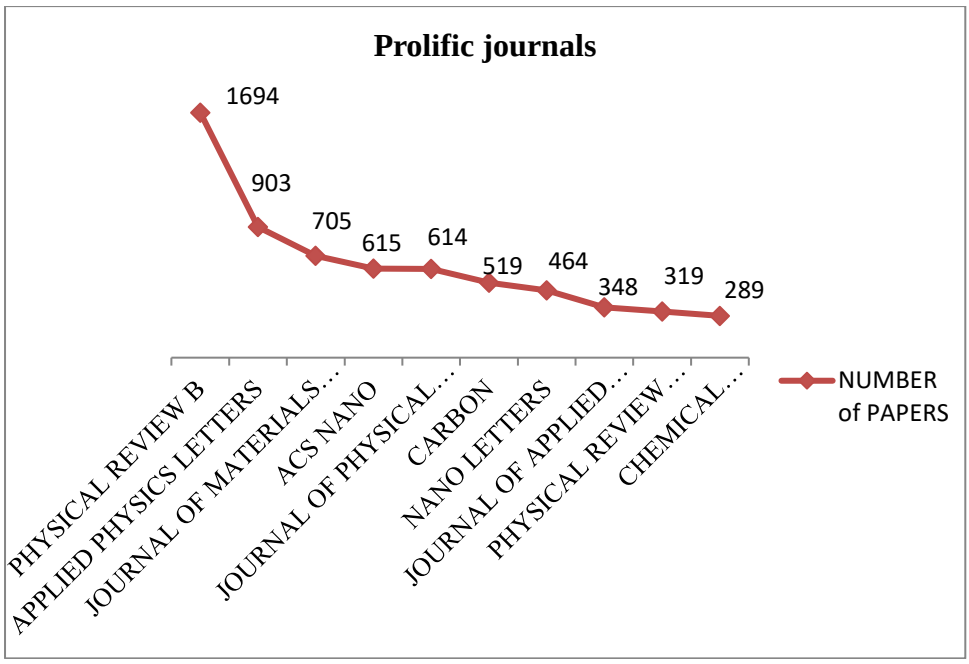
with the findings of **Lv et al. (2011)** and reveals an exponential growth in the production of Graphene literature output.
The increase in article output from 7523, for time period 1991 – 2010 i.e., 20 years (**Lv et al., 2011**) to 16213 for 2010 – 2012 i.e., 3 years, illustrates a tremendous rush of interest graphene has received from researchers, since 2010.



Graph 1: Annual publication production distribution.

2. Prolific Journals

The data analysis reveals that graphene research output, as indexed in WoS, for the three year time period i.e., 2010, 2011 and 2012 has been published in 430 journals of WoS as compared to 382 journals traced by **Lv et al. (2011)** during 20 year time span i.e., 1991 - 2010. The most productive journals, from the publication count, are- Physical Review B comprising of 1694 (11%) publications followed by Applied Physics Letters (903, 6%), Journal of Materials Chemistry (705, 5%), ACS Nano (615, 4%) and Journal of Physical Chemistry C (614, 4%). The study of **Lv et al. (2011)** also confirms the Physical Review B and the Applied Physics Letters as the top productive journals. Approximately, 40% of the papers reside in the top ten most productive journals. Graph 2. presents a clear view of the data distribution.
Thus, a huge number of journals, dealing with almost all fields, publish the research literature pertaining to graphene. The most productive journal from the list of 430 journals is the Physical Review B, thus being the primary journal for graphene research publications since 1991.



Graph 2: Prolific Journals

3. Top Publication based on Citation Score

The highly cited article published in the year 2010 has a total citation score of 7048, up to the year 2017, which equals 881 average number of citations per year. For year 2011, the highly cited paper has 5189 citations with 741 average citations per year and for year 2012, article having 1650 citations up to 2017, which equals average of 275 citations per year, tops the list. Table 1 presents the data distribution of the top three highly cited articles for each year i.e., 2010, 2011 and 2012, respectively.

The findings of **Lv et al. (2011)** revealed that the top cited publication during the time period of 20 years (1991 - 2010), published in 2004, has 3522 citations. Thus, it can be deciphered that the citation rate for the publications have marked a massive increase from year 2010 and thereafter depicts a decreasing trend.

Table 1: Top Publication based on Citation Score

Year	Article	Total Citations (upto 2017)	Avg. Citations Per Year
2010	A consistent and accurate ab initio parameterization of density functional dispersion correction for the 94 elements H – PU.	7048	881
	Atomically Thin MoS2: A New Direct-Gap Semiconductor.	4463	558
	Roll-to-roll production of 30-inch graphene films for transparent electrodes.	4195	524
2011	Single-layer MoS2 transistors.	5189	741
	Carbon-Based Super capacitors Produced by Activation of Graphene.	2729	390
	Two-Dimensional Nano sheets Produced by Liquid Exfoliation of Layered Materials.	2659	380
2012	Laser Scribing of High-Performance and Flexible Graphene-Based Electrochemical Capacitors.	1650	275
	The reduction of graphene oxide.	1416	236
	Silicene: Compelling Experimental Evidence for Graphene like Two-Dimensional Silicon.	1450	242

4. Top Journal based on Citation Score

Among the top ten productive journals, publications of 'ACS Nano' have received the most number (120200) of citations to its 615 publications on graphene and the average citation rate per publication equals 195, followed

by journal 'Nano Letters' having 83700 citations to 464 publications. Physical review B, the most productive journal in terms of number of publications, ranks on the 9th position with total citation count of 66900 averaging 40 citations per paper. Table 2 presents the data distribution for the top ten most productive journals.
From citation statistics journal 'ACS Nano' tops the list despite ranking 4th on the most productive journal list, thus elucidating its greatest impact strength.

Table 2: Top journal based on Citation score

Source Title	**Number of Papers**	**Total Citations**	**Avg. Citations Per Item**
PHYSICAL REVIEW B	1694	66900	39.50
APPLIED PHYSICS LETTERS	903	35700	39.53
JOURNAL OF MATERIALS CHEMISTRY	705	61790	88
ACS NANO	615	120200	195
JOURNAL OF PHYSICAL CHEMISTRY C	614	40700	66.30
CARBON	519	42900	83
NANO LETTERS	464	83700	180
JOURNAL OF APPLIED PHYSICS	348	7500	22
PHYSICAL REVIEW LETTERS	319	36000	113
CHEMICAL COMMUNICATIONS	289	29500	102.10

CONCLUSION

Graphene has been the subject of discussion and research since many years. From five publications in 1991 notable production has been traced since 2005 **(Lv et al., 2011).** The publication production, as found from the present study, is having a rapid evolution since year 2010 and the publication count in 2012 has more than doubled the count of publications in 2010. The publication of 2010 has also gained the highest impact strength. Though some earlier studies provided the initial stages of development in graphene research, this study provides a quantitative analysis of the graphene research for three year time period i.e. 2010, 2011 and 2012, when the field started to progress. The rise in graphene research started emerging after its extraction in 2004 and then showed a massive surge since 2010. The year 2010 has marked a beginning of new era in graphene research as the extraction of graphene was considered a ground-breaking discovery and its scientists were awarded Nobel Prize in the same year, thus sparking researcher attention from around the globe. Therefore, this study would provide a roadmap of the rising journey of graphene research for better planning and policing and would be beneficial for researchers from academia to industry.

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