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Carbon nanotubes: bibliometric analysis of patents

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Abstract

Patents are rich sources of technical and commercial information. Bibliometric analysis of patents provides information on the nature and growth of the inventive activity; its international comparison; the active players from industry, academia and government; co-inventorship; linkages with science; and technological trends. The present paper highlights the results of such a study in the area of carbon nanotubes. The analysis indicates that first patents were filed immediately after the discovery of the carbon nanotubes. The researchers at Nippon Electric Company (NEC) have been most active in the field. There is considerable thrust on patenting in the area of synthesis or processes for production of the carbon nanotubes. The technological trends indicate the possibilities of applications in the areas of nano test tubes, nanoelectronics, and polymer and composite materials. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Patents are rich sources of technical and commercial information. They describe the nature of inventions taking place in a field of technology, the emerging research directions, and the companies and research groups active in the field. The information is important in the sense that much of the technical contents of patents are not published elsewhere. Patent information is more current in contrast to the information published in the scholarly articles or research journals. Most scientists in developing countries do not know how to make use of this information in day-to-day R&D work. The present study aims to highlight the importance of patent information for scientists, technologists and managers in R&D institutions and industry, who are interested in utilizing such information in their respective organizations.

Several studies have indicated the use of the bibliometric techniques to analyze the status and trends in technology development [1,10]. The patenting activity in the field of fullerenes, examined earlier [2], revealed significant applications in the areas of electronics, electrical, chemicals and life sciences. The study indicated an immediate spurt in the patenting activity since their discovery in the 1980s – implying a breakthrough in the technological paradigm shift in the field of fullerene. The carbon nanotubes are fullerene-related structures. These are elongated like a fiber and are hollow. The nanotubes have a hexagonal pattern on their walls. Japanese electron microscopist Iijima [3] discovered carbon nanotubes in 1991, while studying the material deposited on the cathode during the arc-evaporation synthesis of fullerene.

Carbon nanotubes was the most active sub-field of nano science and nanotechnology in 1997. The bibliometric analysis of the growth rate of journal papers with a nano-prefixed word in their title indicated the doubling time of 0.5 yr for nanotubes as against 1.6 yr for other sub-fields with nano-prefixed word in general [4]. The path-breaking paper by Iijima [4] describing the discovery of carbon nanotubes received 555 citations during 1992–1995. Meyer and Persson [5] examined the trends in patenting in the field of nanotechnology for the period 1990–1997 but did not explicitly analyze patents in the sub-field of carbon nanotubes. It may, therefore, be worthwhile to analyze the patenting activity in the area of carbon nanotubes.

2. Data and methodology

The bibliometric data on patents in the field of carbon nanotubes were obtained from the INPADOC/EPIDOS database available with the National

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Informatics Centre, Government of India, New Delhi. The search was made using the search code "carbon nanotube" in the title of patents. The search resulted in bibliometric patent information on 33 patents. In addition to this, the search was also made in esp@cenet world patent database, of EP and US specifications, respectively. The data were obtained for patents filed till the end of August 1999 [6,7]. The search on the esp@cenet patent database resulted in the bibliometric information of 29 patents, while in the US patent database the search resulted in the bibliometric data of 17 patents.

The data obtained from three different databases included information on patent numbers, which were repeated in more than one database. The data was classified according to the patent numbers so as to remove the overlap. After removing the overlap, of the total 89 patents obtained from the three databases, a set of 49 patents was obtained for the bibliometric analysis of patents. The patents filed in more than one country for the same invention were included in the sample as these had different patent numbers assigned to them.

The bibliometric data included information on

- patent No.,
- kind of document,
- date of publishing,
- publishing country,
- title,
- inventor,
- assignee,
- international patent classification,
- application No.,
- date of application,
- applicant country,
- priority.

The data were used to obtain greater insights into the nature and growth of the inventive activity; its international comparison; active players from the sectors of industry, academia and government institutes; co-inventorship; and productivity of inventors. The titles of the patents were used to identify the emerging technological opportunities in the field of carbon nanotubes.

The data on examiner's cited references for 17 US patents were also obtained from the US patent database and the information was used in analyzing the science linkages of the technologies in the field of carbon nanotubes.

3. Analysis of patenting activity

3.1. Growth in patents

Table 1 shows that the patents in the field of carbon nanotubes were first filed in 1992, i.e. within one year of their discovery in 1991. The first patents were published in 1994. The patenting activity in the field reached its peak in 1997, when a maximum number of 14 patents were published. After 1997, the patenting activity slowed down. The slowing down may be due to the reason that the technology in the field was in its nascent stage and a lot more scientific understanding might be required before any further impact on the process of technological development took place.

Table 1
Growth in patenting

By date of priority		By date of publishing	
Year	No. of patents	Year	No. of patents
1992	4	–	–
1993	8	–	–
1994	12	1994	4
1995	12	1995	8
1996	4	1996	10
1997	7	1997	14
1998	1	1998	7
1999	1	1999	6
Total	49		49

3.2. International comparison

Table 2 gives information on country-wise distribution of the patenting activity. Japan and USA are most active in patenting in this field. Of the total 49 patents published in the field, Japan published 20 patents, i.e. 41% of the total, and USA published 17 patents, i.e. 35% of the total. There is no patenting activity by Germany and France, although they made significant contributions in the broader field of nanotechnology during 1990–1997 [5]. None of the countries like Taiwan, Finland, Ireland, Norway, Hong Kong who were reported to be active in patenting in the field of nanotechnology [5] have filed any patents in the field of carbon nanotubes.

Both the countries have preference in domestic filing. Of the total 30 patents from Japan, 63% have been filed within Japan itself, while 37% have been filed outside Japan, mainly, USA. Similarly, of the total 14 patents from USA, 64% have been filed within USA and 36%

Table 2
International comparison (No. of patents)

Applicant country	Publishing country			
	Japan	USA	Others	Total
Japan	19	8	3	30
USA	1	9	4	14
Others	–	–	5	5
Total	20	17	12	49

outside USA. In comparison to patenting by Japanese inventors in USA, few patents have been taken by inventors from US in Japan.

3.3. Sector-wise performance

Schmoch [8] points out that one of the reasons for seeking patent protection is to show an interest in the commercial exploitation of a new technology, and accordingly, most of the patent assignees are industrial enterprises. The field of carbon nanotubes is no different. Table 3 gives information on the patenting activity of players from industries, academia and government R&D institutes. The data clearly indicate that the companies owned 27 patents, i.e. 61% of the total patents in the field. The share of the academia is about 10% of the total patents, while the share of government institutions is 22%. There are two joint patents of companies and academia.

3.4. Active players

Nippon Electric Company (NEC) from Japan is the leading company with the highest number of patents in the field. Researchers from NEC made the discovery of carbon nanotube and have since sustained the lead in technology development. Cannon Inc. and Mitsubishi Chemical company are other two companies from Japan with patents in this field. The companies from USA like Du Pont or General Motors have only one patent each. Although Du Pont was one of the leading players in the field of fullerene [2], it has yet, no significant number of patents in the field of carbon nanotubes.

The academic institutions from USA are most active in patenting in the field. These are University of Northwestern Arizona and University of Rice Williams. The University of Florida has jointly taken two patents with NEC. Of the total number of 11 patents by government institutes, the institutes from Japan have filed 10 patents; of which, nine patents are from Agency for Industrial Science and Technology. There is no patenting activity by government institutes from US.

Table 3
Sector-wise performance of the patenting activity (no. of patents)

Assignee	Publishing country			
	Japan	USA	Others	Total
Companies	15	8	4	27
Academia	–	1	4	5
Government institutes	4	5	2	11
Individuals	1	1	2	4
Joint companies and academia	1	1	–	2
Total	21	16	12	49

3.5. Co-inventorship

A patent application includes the names of all those contributors/researchers as co-inventors who make direct contributions to the patentable features of the invention. The pattern of co-inventorship in the field of carbon nanotubes indicates that R&D teams consisting of two inventors have filed the maximum number of 21 patents, i.e. 43% of the total. In fact, 33 patents, i.e. 67% of the inventions have come from teams of one or two inventors. Patents from teams of three and six inventors each are only 12% of the total inventions.

3.6. Productivity of inventors

The data on inventorship were further analyzed to find out the total number of patents owned by each inventor. Table 4 gives the data of productivity of inventors. It is observed that one inventor was associated with a maximum number of eight patents. Two inventors were associated with seven patents each, three inventors with six patent each, four inventors produced three patents each, 12 inventors two patents each, while a large number – 40 inventors produced only one patent each. This pattern seems to follow the Lotka's law, in the sense, that for an equal number of core patents, the number of inventors is a constant multiple of the inventors in the core.

3.7. Science linkages

Karki [9] reviewed the literature on concepts and techniques of patent citation analysis. These techniques utilize citations in patent documents as a means of studying the linkages between science and technology. Narin [10,11] and his colleagues at Computer Horizons, USA, have done the pioneering work in this field. The term non-patent literature (NPL) indicates a reference of a publication cited in a patent document. Grupp and Schmoch [12] developed a quantitative measure of the index of NPL cited in patent documents. According to them, the mean NPL index is obtained by dividing the total number of citations in a technology field by the total number of patents citing the NPL references.

Table 4
Productivity of individual inventors

No. of patents	No. of inventors
8 each	1
7 each	2
6 each	3
5 each	1
4 each	–
3 each	4
2 each	12
1 each	40

Table 5
NPL citations[a]

No. of patents	No. of NPL citations/patent	Total No. of NPL citations
1	43	43
1	17	17
1	12	12
1	9	9
1	7	7
1	6	6
2	5	10
2	4	8
3	2	6
1	1	1
3	0	0

[a] Mean NPL index = 119/17 = 7.0.

Table 6
Immediacy/age of NPL citations

Age of cited NPL (yr)	No. of citations
0	13
1	35
2	20
3	17
4	3
5	4
6	3
7	1
10–20	12
20–30	6
30–40	3
Above 40	1

Table 5 gives the information on NPL citations of patents in the area of carbon nanotubes. The mean NPL index comes out to be seven citations per patent in the field of carbon nanotubes. Table 6 examines the age of the NPL cited in the patent documents. The age of a citation is calculated by subtracting the year of publication of the cited reference from the year of the patent that cites the reference. About 58% of the total citations belong to the most current literature appearing in the field. The literature, which is three to seven years old, receives 24% citations, while 17% citations are to literature, which is more than 10 yr old. This shows that a larger proportion of the basic knowledge, which is published in the literature, is of immediate relevance for the inventive activity leading to patents in this field.

3.8. Highly-cited journals/authors

Table 7 indicates that a small number of core journals serve as a source of scientific information to patentable inventions in the field of carbon nanotubes. There is a strong contribution of basic knowledge from two journals, namely, Nature and Carbon. Nature is an interdisciplinary journal at the cutting edge of scientific research. Carbon is a specialized chemistry journal. Since the basic technology concerns one of the allotropes of carbon itself, it is not surprising that it receives high citations. There are also significant citations from physics- and other chemistry-based journals.

Table 7
Highly-cited journals

S.No.	Name of the journal	No. of citations
1	Nature	35
2	Carbon	15
3	Journal of Catalysis	8
4	Applied Physics Letters	8
5	Chemical Physics Letters	6
6	Physical Research Letters	5
7	Science	5
8	Journal of Physical Chemistry	5
9	Others – 16	30
10	Total number of journals – 24	117

Vinkler [13] defines the index of journal references concentration as the percentage share of journals containing 50% of total papers referred to. In the case of carbon nanotubes, 50% of the references are covered by only three journals, i.e. 12.5% of the total 24 journals. In contrast, the concentration of the referenced items in pharmaceutical patents was 14–23% of the total journals [14].

The analysis of authors whose work has been cited in the patents indicates that the field is characterized by the property that the researchers publishing in scholarly journals are also active in the field of patenting. The researchers from industry are not only leading in taking patents but also publishing in the scholarly journals, communicating and sharing their results with other scientific colleagues. This may be with the hope to attract academic researchers in the process of technology development, which is still in the nascent stage. The scientists in the companies also publish to inform their scientific competence to the academic researchers. This is similar to the findings of Noyons et al. [14] that for medical lasers – the science-based field – most inventors are also actively engaged in publishing a number of publications related to the area of invention.

3.9. Technological trends

Nanotechnology is an emerging technology field. This is one of the key technologies likely to revolutionize information technology, materials and medicine. Researchers at NEC found the way to produce nanotubes in higher yields and make them available for studies by different techniques. Subsequently, they found a way to purify them. Although Iijima's [3] first observations were of multi-wall nanotubes, he observed single-wall carbon nanotubes less than two years later. In 1996, the researchers at the William Rice University synthesized bundles of single-wall carbon nanotubes for the first time. It opened new opportunities for quantitative experimental studies on carbon nanotubes.

The emerging technological opportunities and research directions in the area of carbon nanotubes were analyzed using the bibliometric data on patents. The key words in the title of the patents were used to classify a particular patent into one or the other technological fields. From the analysis of data, we observe that the maximum number of 24 patents (49%) is related to the synthesis or processes or the production of carbon nanotubes. There are seven patents on the structure and models of nanotubes and the properties of nanotubes. The emphasis is on the methods that produce high yields of nanotubes at low cost, which is quite essential from the point of view of application. Some sort of continuous process may probably be needed to grow carbon nanotubes on a commercial scale.

There are 18 patents (37%) relating to the technological applications. Carbon nanotubes are unique nanostructures with remarkable electronic and mechanical properties. The patenting activity in carbon nanotubes indicates that nanoelectronics wherein, five patents have been filed, is an area of emerging technological opportunities. Theorists have shown that nanotubes can be conducting or insulating depending on their structure which may lead to applications in nanoelectronics.

The technological applications in the field of polymer and composite materials are equally important as theory suggests that nanotubes are likely to be immensely strong. There are four patents already filed in this area. The carbon nanotubes are so small that they could be used in polymer composites or as low-viscosity composites that could be sprayed onto a surface as conducting paint or coating. The nanotubes research has demonstrated that tubes can be opened and filled with a variety of materials including biological molecules. The inventions in the areas of nano test tubes, which exploit the hollowness properties of carbon nanotubes signify key technological opportunities.

Single-walled nanotubes now can be produced in yield proportions of more than 70%. These nanotubes self-organize into bundles–ropes more than one-tenth of a millimeter long that look very promising for engineering applications. However, the patent analysis indicates that there is yet no significant patenting in the direction of engineering application.

4. Conclusions: the future

As we learn more about carbon nanotubes, producing novel electronic devices and composite materials could just be the start of a variety of future applications. It is too early to make reliable forecasts of commercial potential, although the early indications are that such structures may represent a technological bonanza when their properties are fully understood. These developments are a strong reminder that fundamental science is often the wellspring of advanced technology in ways that are completely unpredictable.

References

[1] Karki MMS. Bibliometric analysis of patents: implications for R&D and industry, emerging trends in scientometrics. In: Nagpaul PS et al., editor. New Delhi: Allied Publishers, 1999.
[2] Gupta VK. Technological trends in the area of fullerenes using bibliometric analysis of patents. Scientometrics 1999;44(4):17–31.
[3] Iijima S. Nature 1991;354:56.
[4] Braun T, et al. Nanoscience and nanotechnology on the balance. Scientometrics 1991;38(2):321–5.
[5] Meyer M, Persson O. Nanotechnology – interdisciplinarity, patterns of collaboration and differences in applications. Scientometrics 1998;42(2):195–205.
[6] esp@cenet: patent searching, e.g. at http://www.ipr-helpdesk.org.
[7] http://www.uspat.gov.
[8] Schmoch U. Indicators and the relations between science and technology. Scientometrics 1997;38(1):103–16.
[9] Karki MMS. Patent citation analysis: a policy analysis tool. World Patent Inf 1997;19(4):269–72.
[10] Narin F. Patent bibliometrics. Scientometrics 1994;30(1):147–55.
[11] Narin F. Patent indicators for the evaluation of industrial research output. Scientometrics 1995;34(3):489–96.
[12] Grupp H, Schmoch U. Perceptions of scientification of innovation as measured by referencing between patents and papers. In: Grupp H, editor. Dynamics of science based innovations. Berlin: Springer, 1992.
[13] Vinkler P. The origin and features of information referenced in pharmaceutical patents. Scientometrics 1994;30(1):283–302.
[14] Noyons ECM, Van AFJ, Raan H, Grupp U, Schmoch U. Exploring the science and technology interface: inventor–author relations in laser medicine research. Res Policy 1994;23:443–57.

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