

Worldwide nanotechnology development: a comparative study of USPTO, EPO, and JPO patents (1976–2004)

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Abstract To assess worldwide development of nanotechnology, this paper compares the numbers and contents of nanotechnology patents in the United States Patent and Trademark Office (USPTO), European Patent Office (EPO), and Japan Patent Office (JPO). It uses the patent databases as indicators of nanotechnology trends via bibliographic analysis, content map analysis, and citation network analysis on nanotechnology patents per country, institution, and technology field. The numbers of nanotechnology patents published in USPTO and EPO have continued to increase quasi-exponentially since 1980, while those published in JPO stabilized after 1993. Institutions and individuals located in the same region as a repository's patent office have a higher contribution to the nanotechnology patent publication in that repository ("home advantage" effect). *The*

USPTO and EPO databases had similar high-productivity contributing countries and technology fields with large number of patents, but quite different high-impact countries and technology fields after the average number of received cites. Bibliographic analysis on USPTO and EPO patents shows that researchers in the United States and Japan published larger numbers of patents than other countries, and that their patents were more frequently cited by other patents. Nanotechnology patents covered physics research topics in all three repositories. In addition, USPTO showed the broadest representation in coverage in biomedical and electronics areas. The analysis of citations by technology field indicates that USPTO had a clear pattern of knowledge diffusion from highly cited fields to less cited fields, while EPO showed knowledge exchange mainly occurred among highly cited fields.

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Introduction

Nanotechnology has been recognized as a key technology of the 21st century. Due to its implications and rapid development, nanotechnology has

already been identified as a critical indicator for a country's technological competence. In 2000, the United States announced the National Nanotechnology Initiative (NNI, <http://www.nano.gov>) based on a long-term vision (Roco et al. 2000). Since then, more than 60 countries have adopted national projects or programs partially stimulated by the establishment of the NNI (Roco 2005). Comprehensive assessments of nanotechnology development are not only necessary for research policy decisions but are also of interest to academic and industry communities.

Patent analysis has been used to assess innovation, research and development of a technology field (Karki 1997; Narin 1994; Oppenheim 2000). In the nanotechnology domain, Huang et al. (2003) performed a longitudinal analysis of nanotechnology patent publications of different countries, institutions, and technology fields and, in a later study, investigated the impact of National Science Foundation funding on nanotechnology patents (Huang et al. 2005).

Patent publication is managed by specialized offices in different countries. In general, inventors can file their patents in one or more countries. However, domestic applicants tend to file more patents with their home country patent office than do foreign applicants (European Commission 1997). This “home advantage” effect influences the composition of the patents in the patent repositories. In previous research, Ganguli (1998) observed the home advantage effect in patents filed in USPTO, EPO, and JPO during 1995 and 1996. Criscuolo (2005) determined that patents filed by multinational enterprises in EPO and USPTO showed strong home advantage effects in every technology area. The existence of the home advantage effect indicates that individual patent office repositories may not provide a comprehensive coverage of all patents in a technology domain.

Patent offices have different policies and examination procedures, which may also affect the patents filed in their repositories. For example, in the USPTO Duty of Disclosure, Candor, and Good Faith rule requires applicants to disclose and cite all prior related work of which they are aware. However, the EPO has no such requirement. Most EPO patent citations were added by examiners. For this reason, USPTO patents usually have more citations per patent than do EPO patents (Bacchiocchi and Montobbio 2004). Also, a larger proportion of USPTO patent applications are granted than are EPO applications (Quillen et al. 2002).

The inventors' preferences and the patent offices' policies affect both contents of the patents and the coverage of the repositories. Hence, it is necessary to study the patents filed in multiple patent offices to obtain a comprehensive view of a technology area's development status. In other domains, patent analysis studies have combined data from different patent offices. For example, to determine the contribution of Italian professors to patents owned by science-based technological companies, Balconi et al. (2004) studied the patents in both the USPTO and EPO. Lukach and Plasmans (2001) also examined both repositories in their study of inter-firm and intra-firm knowledge diffusion patterns using patents published by Belgian Companies. However, in the nanotechnology field, few studies have employed multiple repositories to reveal its research and development status. Previous nanotechnology patent analyses may be biased by the characteristics of individual databases.

Our previous research showed that the United States and Japan and European countries played an important role in worldwide nanotechnology research. Thus, we focus on the nanotechnology patents at the USPTO, EPO, and JPO, which may cover a large cross-section of the nanotechnology research efforts in the world. Although several other countries, such as Germany, China, Republic of Korea, and France, also have significant numbers of patents, we do not consider them in this comparative research because their contributions are relatively smaller and the patent documents contain too many language and format differences. We analyze the English patents documented in the three repositories using three types of analysis techniques: bibliographic analysis, content map analysis, and citation network analysis, similar to Huang et al. (2004, 2003).

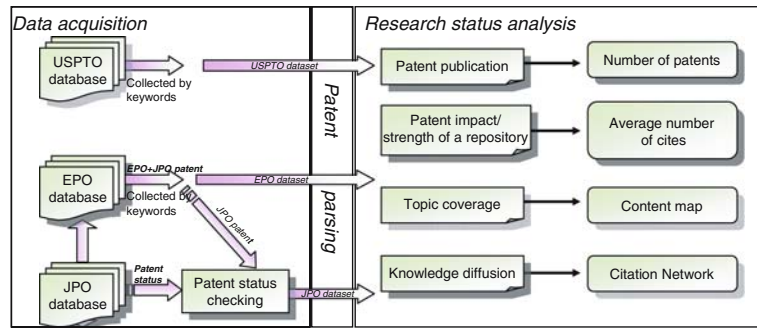
Methods

Our research methodology contains three steps: data acquisition, patent parsing, and research status analysis (Fig. 1).

Data acquisition

The nanotechnology patents were identified in the USPTO, EPO, and JPO databases using the list of nanotechnology keywords given in Table 1 and

Fig. 1 Outline of the research methodology



provided by experts working in nanotechnology (Huang et al. 2004, 2003). Each of the three atabases provides an online search interface

- The USPTO database provides the full-text of the patents issued since 1976, which can be searched using almost all of a patent’s data fields.
- The EPO repository, esp@cenet, documents EPO patents issued since 1978 together with patent applications from the patent offices of more than 70 countries. This system supports search on title, abstract, and some of the bibliographic data.
- The JPO official patent database, Patent Abstracts of Japan (PAJ), contains the patents issued since 1976.

Due to the system design, the PAJ database is difficult to search. However, because its patents and patent applications are documented in esp@cenet, we retrieve JPO data from esp@cenet, check the retrieved patents’ status (whether application or registered patent) through PAJ, and remove the ongoing applications from the dataset.

In our previous research, we retrieved nanotechnology patents from the USPTO database by searching the nanotechnology-related keyword list in each patent’s title, abstract, and claims (“title-claims” search) as well as in all patent data fields (“full-text” search) (Huang et al. 2004, 2003). Due to the search function limitations of esp@cenet, we can only collect nanotechnology patents in EPO and JPO by searching the keyword list in patent title and abstract (“title-abstract” search). To be comparable with the patents retrieved from these two databases, in this research we also collected the USPTO dataset using “title-abstract” search.

Table 1 shows the number of patents retrieved in the three databases using different approaches.

“Title-abstract” search provides significantly fewer search results than our previous methods (“title-claims” and “full-text”). However, the numbers of patents retrieved by different keywords are proportional to each other across the three search methods. After inspecting the data, domain experts believe that using the “title-abstract” search in the three databases is appropriate and can provide consistent results for making comparisons across the three repositories.

Patent parsing

The nanotechnology patents retrieved from USPTO, EPO, and JPO are in free-text. First, we parse the free-text data into structured data. Table 2 lists the data fields used in this research (the “applicant” in EPO and JPO means “assignee” in USPTO). Since JPO patents do not contain assignee country and patent citation information, we are unable to study the publication trend of assignee country and country group and the citation networks of the JPO patents.

We use the classification codes assigned by each patent office to represent the patent’s technology field. USPTO supports United States Patent Classification (USPC) and International Patent Classification (IPC) codes. EPO and JPO support European Patent Classification (EPC) and IPC codes. To compare the patents in the three databases, we adopt IPC as a representation of patent technology fields.

IPC is a five-level hierarchical ontology that contains eight first-level categories (“section”), 120 second-level categories (“class”), and 631 third-level categories (“subclass”). In this research we use the subclass IPC categories to represent technology fields in order to compare these results to those of our previous studies using the equivalent 462 class categories in USPC.

Table 1 Nanotechnology keywords and respective number of retrieved patents

	USPTO (1976–2004)			EPO (1978–2004)	JPO (1976–2004)
	Full-text search	Title-claims search	Title-abstract search	Title-abstract search	Title-abstract search
Atomic force microscope	2,309	375	241	69	62
Atomic force microscopic	53	2	2	2	1
Atomic force microscopy	1,679	103	68	21	0
Atomic-force-microscope	6	0	0	0	0
Atomic-force-microscopy	3	0	0	0	0
Atomistic simulation	5	0	0	0	0
Biomotor	6	1	0	0	0
Scanning tunneling microscope	1,097	205	145	47	79
Scanning tunneling microscopic	21	1	0	0	1
Scanning tunneling microscopy	809	50	28	8	0
Scanning-tunneling-microscope	24	0	0	0	0
Scanning-tunneling-microscopy	1	1	0	0	0
Molecular device	164	13	6	4	3
Molecular electronics	284	3	3	3	3
Molecular modeling	1,787	37	26	2	1
Molecular motor	88	3	0	3	0
Molecular sensor	31	7	0	2	1
Molecular simulation	43	2	2	1	1
Nano*	72,762	12,220	4,497	2,024	635
Quantum computing	66	25	19	4	1
Quantum dot*	609	185	117	49	81
Quantum effect*	563	58	36	16	65
Selfassembl*	23	4	2	0	0
Self assembly	1,802	192	121	33	0
Self assembled	1,682	297	170	31	1
Self assembling	877	158	111	48	5
Self-assembly	1,625	173	108	0	5
Self-assembled	1,587	277	158	0	0
Self-assembling	807	147	102	0	0
Total	90,813	14,539	5,962	2,367	945
Unique Total	78,609	13,463	5,363	2,328	923

Research status analysis

We analyze the patents at three analytical levels:

- country (country group),
- assignee institution, and

- technology field (represented by subclass IPC categories).

We assess the nanotechnology field's research status from four perspectives:

Table 2 Data fields of USPTO, EPO, and JPO patents

	USPTO	EPO	JPO
Patent ID	✓	✓	✓
Publication date	✓	✓	✓
Inventor name	✓	✓	✓
Assignee (applicant) institution name	✓	✓	✓
Assignee (applicant) country	✓	✓	N/A
Patent classification code	IPC	IPC	IPC
	USPC	EPC	EPC
Patent citation information	✓	✓	N/A
Title	✓	✓	✓
Abstract	✓	✓	✓
Claim	✓	✓	✓
Description	✓	✓	✓

- First, we identify the number of patent publications by country (and country group), assignee institution, and technology field.
- Secondly, we use the average number of citations per patent (average number of cites) to assess the degree to which different countries, assignee institutions, and technology fields have influenced and/or dominated the nanotechnology field in the three repositories.
- Thirdly, we generate the content maps of the three repositories’ patents in different time intervals and compare which nanotechnology topics dominated each time period.

Table 3 Types of analysis covered by USPTO, EPO, and JPO

	USPTO	EPO	JPO
Patent publication trend			
Number of patents by country in each year	✓	✓	No
Number of patents by country group in each year	✓	✓	No
Number of patents by assignee institution in each year	✓	✓	✓
Number of patents by technology field in each year	✓	✓	✓
Patent impact			
Average number of cites by country	✓	✓	No
Average number of cites by assignee institution	✓	✓	No
Average number of cites by technology field	✓	✓	No
Topic coverage			
Content map analysis	✓	✓	✓
Knowledge diffusion			
Country citation network analysis	✓	✓	No
Assignee institution citation network analysis	✓	✓	No
Technology field network analysis	✓	✓	No

- Lastly, we analyze the citation network created by each country, assignee institution, and technology field to explore the knowledge diffusion of the invention process (as noted above, citation analysis could not be performed for JPO patents).

Table 3 lists the types of analysis we were able to conduct in all three repositories.

Describing the data

USPTO

The USPTO database has more than 6.5 million patents with 3,500–4,000 newly granted patents each week. In May 2005 we conducted a “title-abstract” search in the USPTO using the nanotechnology keyword list (Huang et al. 2003) and collected 5,363 USPTO nanotechnology patents published between 1976 and 2004 (US patents granted before 1976 do not have full-text access). These patents were submitted by 2,196 assignee institutions, 8,405 inventors, and 46 countries.

EPO

The EPO database has more than 1.5 million patents with more than 1,000 newly granted patents each week. The “title-abstract” search we conducted in

esp@cenet in May 2005 identified 2,328 nanotechnology patents published between 1978 and 2004 (the EPO database does not document its patents before 1978). These patents were submitted by 1,168 assignee institutions, 5,400 inventors, and 43 countries.

JPO

The JPO database has more than 1.7 million patents with 2,000–3,000 newly granted patents each week. We retrieved the patents using “title-abstract” search in esp@cenet and checked their publication status in PAJ. We collected 923 JPO registered patents submitted by 348 assignee institutions and 1,729 inventors (JPO patents do not contain country information) between 1976 and 2004.

Table 4 and Fig. 2 present the numbers of nanotechnology patents published in the three repositories in each year. From the log-scale graph of Fig. 2, we observe that the numbers of nanotechnology patents in USPTO and EPO roughly show an exponential growth. JPO patents show a rapid increase before 1993 and a stable number of nanotechnology patent publications after that date (about 50–86 patents per year).

Bibliographic analysis

We use the number of patents published by each country (and country group), assignee institution, and technology field to assess their productivity in nanotechnology. We analyze the impact using the average number of cites the patents received. We counted a patent’s number of citations only in the collected patent dataset (using “title-abstract” search). We calculated the average number of citations for each country (country group), assignee institution, and technology field.

Country analysis

Top country analysis

Tables 5 and 6 show the top 20 assignee countries, which have the most nanotechnology patent publications in USPTO and EPO. The JPO patents do not contain assignee country information. We observe

Table 4 Number of nanotechnology patents collected by “title-abstract” search in USPTO (1976–2004), EPO (1978–2004), and JPO (1976–2004) in each year

Year	Nanotechnology patents		
	USPTO	EPO	JPO
1976	9	0	0
1977	18	0	0
1978	23	0	0
1979	11	0	1
1980	15	3	1
1981	25	3	0
1982	25	5	1
1983	24	6	1
1984	25	7	4
1985	33	7	1
1986	27	9	8
1987	46	10	0
1988	39	23	8
1989	65	24	6
1990	57	47	13
1991	85	35	29
1992	121	28	46
1993	123	42	45
1994	128	67	70
1995	160	73	65
1996	205	71	66
1997	238	93	51
1998	297	112	54
1999	367	125	78
2000	422	141	86
2001	524	235	78
2002	582	308	83
2003	739	364	78
2004	930	478	50

that the top 20 assignee countries and their rankings are very similar in both repositories, with the United States publishing the most patents in both databases. Although their ranks are reversed in USPTO and EPO, Japan and Germany have the most patent publications after the United States, followed by France and Republic of Korea. Canada and China (Taiwan) have much higher ranks and numbers of patents in the USPTO than in EPO; which may indicate that the inventors in these two countries prefer to file patents in USPTO. On the other hand, inventors in Switzerland prefer to file patents in EPO.

Fig. 2 Number of nanotechnology patents collected by “title-abstract” search in USPTO (1976–2004), EPO (1978–2004), and JPO (1976–2004) each year

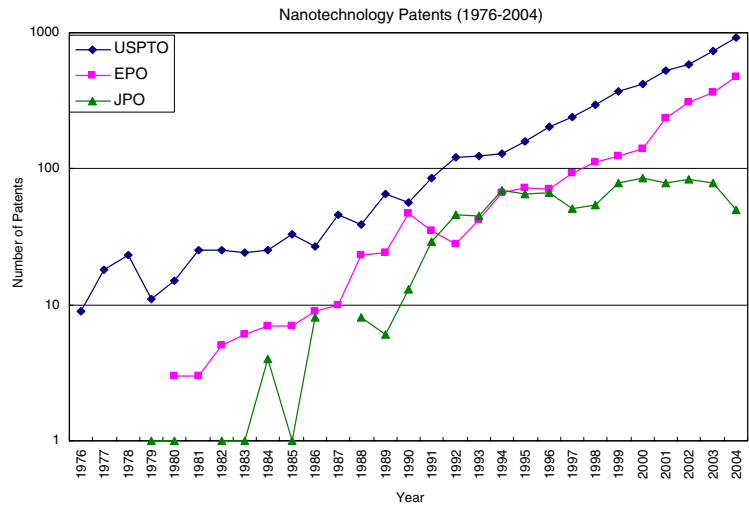


Table 5 Top 20 nanotechnology patent assignee countries in USPTO (“title-abstract” search, 1976–2004)

Rank	Assignee country	Number of patents
1	United States	3,450
2	Japan	517
3	Germany	204
4	France	156
5	Republic of Korea	131
6	Canada	104
7	China (Taiwan)	71
8	United Kingdom	60
9	Netherlands	54
10	Switzerland	41
11	Australia	34
12	Belgium	24
13	Israel	21
14	Italy	20
15	Ireland	20
16	Sweden	18
17	India	14
18	Spain	12
19	China	9
20	Singapore	8

Table 6 Top 20 nanotechnology patent assignee countries in EPO (“title-abstract” search, 1978–2004)

Rank	Assignee country	Number of patents
1	United States	925
2	Germany	343
3	Japan	323
4	France	201
5	Republic of Korea	98
6	Switzerland	77
7	United Kingdom	72
8	Netherlands	51
9	Belgium	42
10	Italy	34
11	Canada	26
12	Ireland	26
13	Spain	22
14	Israel	20
15	Sweden	18
16	Australia	14
17	Austria	13
18	China	9
19	Finland	7
20	India	7

Figures 3 and 4 show the yearly patent publication trends of the top 10 assignee countries in the USPTO and EPO in log scale. Many of the top 10 assignee countries had an increasing trend of nanotechnology patent publication in both repositories. The United States filed more nanotechnology patents than other

countries in almost every year, and the number of US patents grew exponentially in both repositories. In the USPTO database, Japanese patents had a rapid growth before 1994 and then slowed. In the EPO database, Japanese patents remained relatively steady between 1989 and 2000. After 2000, the number of

Fig. 3 Top 10 Nanotechnology assignee countries in USPTO database and their patents by year (“title-abstract” search, 1976–2004) (log scale)

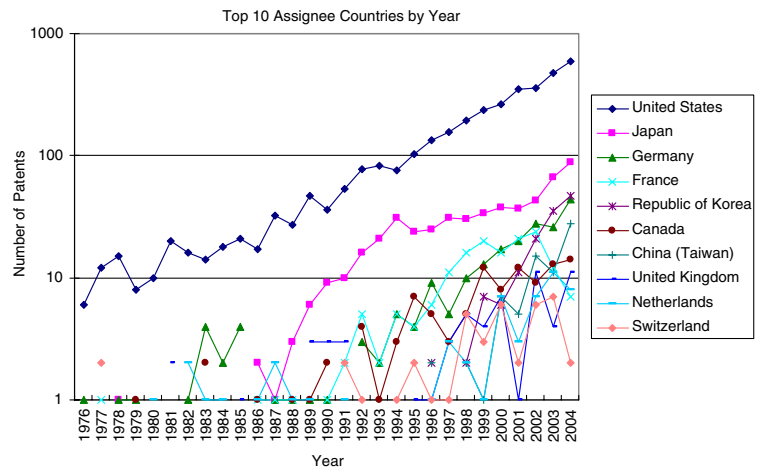
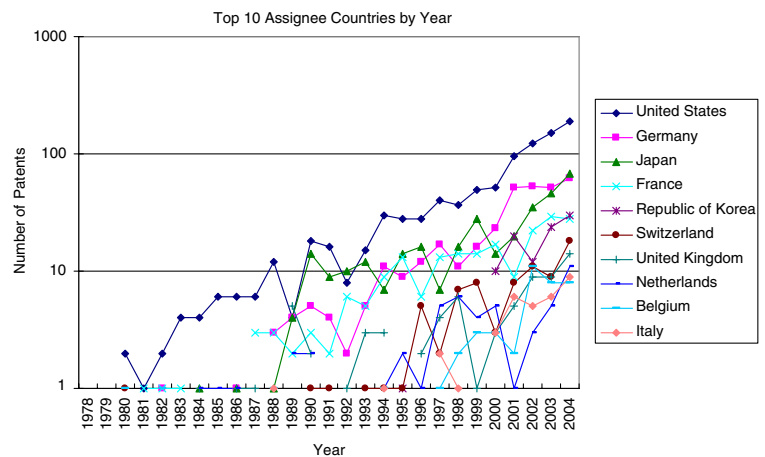


Fig. 4 Top 10 Nanotechnology assignee countries in EPO database and their patents by year (“title-abstract” search, 1978–2004) (log scale)



Japanese patents in EPO grew rapidly. Although the number German patents in the USPTO was continuously increasing, the number published in the EPO was static after 2000. While the number of patents from France was consistently increasing in the EPO, the yearly publication of French patents in the USPTO decreased after 2002. The differences in these countries’ publication patterns in the two repositories show the change of inventors’ interests in the two repositories and changes in the markets of the United States and Europe.

Country group analysis

We organize and compare the patent publication status of four country groups: the United States, European group (25 countries in the European Union, plus Switzerland), Japan, and what we define as the

Others group, which is all the other countries represented in these patent databases.

Table 7 and Fig. 5 (in log scale) show the number of patents filed by the four country groups in the USPTO database from 1976 to 2004. In this database, the United States filed more patents than the other three groups. The European group, Japan, and the Others have similar numbers of nanotechnology patents each year.

Table 8 and Fig. 6 (in log scale) show the number of patents filed by the four country groups in the EPO database from 1978 to 2004. From the graph, we observe that the numbers of patents filed by the United States and European group countries were at the same level in EPO. The numbers of patents filed by Japan and Other countries were at the same level after 1998. In general, these latter two groups filed fewer patents than the United States and the European group.

Table 7 Patent publication trend by assignee country group in USPTO (“title-abstract” search, 1976–2004)

Year	United States	European group	Japan	Others
1976	6	1	0	1
1977	12	1	0	2
1978	15	1	1	2
1979	8	1	0	1
1980	10	1	0	0
1981	20	3	0	1
1982	16	4	0	0
1983	14	5	0	2
1984	18	4	0	0
1985	21	5	0	0
1986	17	2	2	1
1987	32	4	1	0
1988	27	4	3	2
1989	47	7	6	2
1990	36	5	9	3
1991	53	10	10	2
1992	77	9	16	6
1993	82	6	21	4
1994	76	11	31	4
1995	102	11	24	14
1996	135	17	25	14
1997	157	26	31	8
1998	196	40	30	19
1999	237	45	34	28
2000	262	59	38	35
2001	348	63	37	43
2002	358	83	43	71
2003	478	73	66	92
2004	590	83	89	120

In both USPTO and EPO, the number of nanotechnology patents published by the four country groups increased. Comparing Figs. 5 and 6 and Tables 7 and 8, we see that the United States filed many more nanotechnology patents in USPTO than in EPO. On the other hand, European group countries filed a few more patents in EPO than in USPTO. Japan and Other countries filed similar numbers of patents in both databases. These phenomena show that inventors tend to file patents in their own countries’ patent offices more often than in foreign countries’ patent offices.

Analysis of country impact

We use the average number of cites measure to identify the high impact nanotechnology assignee countries in USPTO and EPO. Tables 9 and 10 show the top 10 assignee countries based on the average number of cites measure. To keep the analysis meaningful, we only study the countries with more than 10 patents. In general, the average number of cites measures in USPTO are much higher than those in EPO, which may be due to the two patent offices’ policies: USPTO requires inventors to cite previous works in their patents, while EPO doesn’t (Bacchiocchi and Montobbio 2004). Although five out of the 10 high impact countries (United States, Japan, Switzerland, France, and Israel) are the same in the two datasets, their rankings are significantly different. Compared with the top 20 assignee countries in Tables 5 and 6, we find that although the high productivity countries are very similar in the two repositories, the high impact countries are different. Among the high impact countries, the United States and Japan published many of the patents with high average number of cites in both repositories, indicating their important roles in international nanotechnology development.

Assignee institution analysis

Top assignee institutions

Tables 11–13 report the 20 assignee institutions having with the most nanotechnology patent publications in all three databases (the country attribute of JPO in Table 13 is identified manually). We also report the average patent ages (the average number of years the patents had been published, up to 2004) for each institution (Huang et al. 2003). A shorter average patent age indicates that the institution has become more active in recent years.

In the USPTO, International Business Machines Corp. (IBM) produced the most nanotechnology patents, followed by The Regents of the University of California, The United States of America as represented by the Secretary of the Navy, Eastman Kodak Co., and Minnesota Mining and Manufacturing Co. (3M Co.). The top USPTO assignee institutions, in general, had an average patent age of about 5 years, which are long histories in nanotechnology

Fig. 5 Patent publication trend by assignee country group in USPTO database (“title-abstract” search, 1976–2004) (log scale)

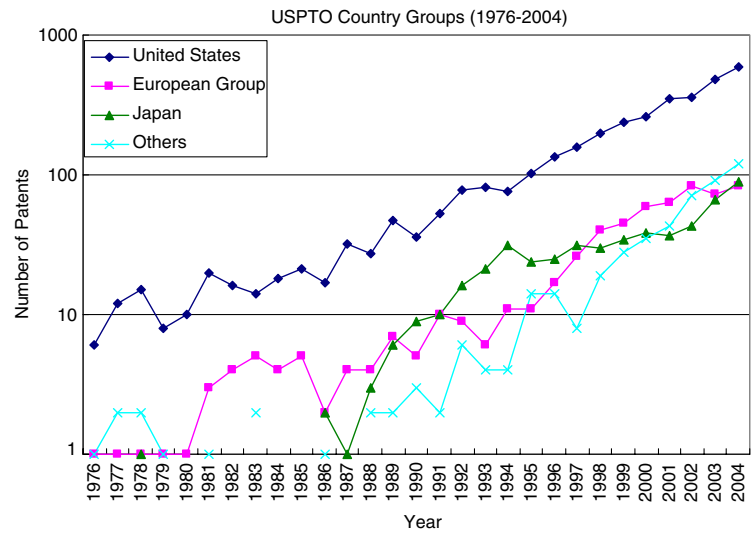


Table 8 Patent publication trend by assignee country group in EPO database (“title-abstract” search, 1978–2004)

Year	United States	European group	Japan	Others
1978	0	0	0	0
1979	0	0	0	0
1980	2	1	0	1
1981	1	1	0	0
1982	2	3	0	0
1983	4	2	0	0
1984	4	1	1	1
1985	6	1	0	0
1986	6	2	1	0
1987	6	4	0	0
1988	12	8	1	1
1989	4	12	4	1
1990	18	13	14	3
1991	16	8	9	2
1992	8	9	10	1
1993	15	14	12	1
1994	30	29	7	2
1995	28	27	14	5
1996	28	22	16	6
1997	40	45	7	3
1998	37	46	16	13
1999	49	39	28	10
2000	52	56	14	19
2001	95	85	20	36
2002	122	118	35	37
2003	150	123	46	54
2004	190	154	68	75

research. Micron Technology, Inc., Advanced Micro Devices, Inc., the California Institute of Technology, and Hewlett-Packard Development Company, L.P., had relatively smaller average patent ages (2 years), but with significant numbers of patents published in the USPTO database. These four assignees were relatively more active in recent years.

In the EPO, French cosmetic company L’Oreal held the most patents, followed by IBM, Rohm & Haas (an American special materials company), Eastman Kodak Co., and Samsung Electronics Co. Ltd. In general, the average ages of the top 20 EPO assignee institutions’ patents are 4 years. However, Samsung Electronics Co. Ltd., Japan Science and Tech. Agency, and Henkel Kga had much smaller average patent ages than the other institutions, indicating their active innovations in recent years. IBM is the second largest assignee institution in terms of nanotechnology patent publication. However, its average patent age is 11.91 years, which shows its long history in the field. It has fewer patents published in recent years.

In the JPO, Nippon Electric Co. is the largest assignee institution, followed by Japan Science and Tech. Corp., Agency of Industrial Science and Technology, Matsushita Electric Industrial Co. Ltd., and Tokyo Shibaura Electric Co. Most of the top 20 assignees in JPO had an average patent age of more than 7 years. However, Japan Science and Tech. Corp., National Institute for Materials Science, and National Institute of Advanced Industrial Science and Technology had an average patent age of fewer than

Fig. 6 Patent publication trend by assignee country group in EPO database (“title-abstract” search, 1978–2004) (log scale)

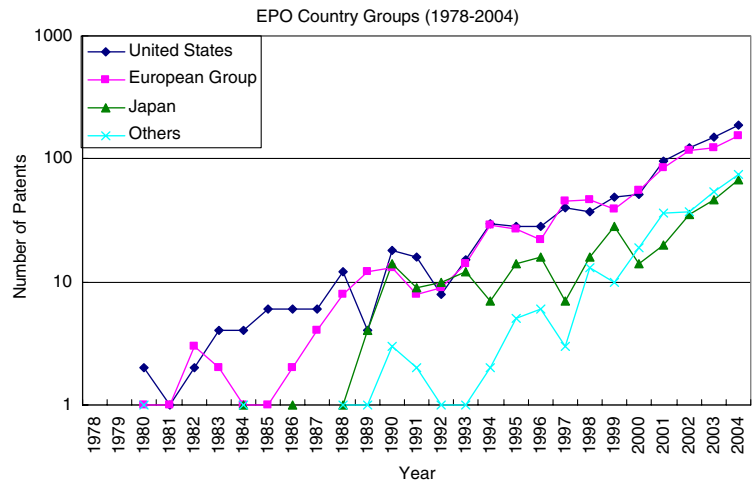


Table 9 USPTO top 10 countries with more than 10 patents based on the average number of cites measure (“title-abstract” search, 1976–2004)

Country name	Number of patents	Average number of cites
Australia	34	2.09
Japan	517	1.90
Switzerland	41	1.90
United States	3,450	1.81
Ireland	20	1.55
Canada	104	1.30
France	156	1.10
China (Taiwan)	71	0.89
Germany	204	0.89
Israel	21	0.86

Table 10 EPO top 10 countries with more than 10 patents based on the average number of cites measure (“title-abstract” search, 1978–2004)

Country name	Number of patents	Average number of cites
Japan	326	0.22
Spain	22	0.18
Belgium	42	0.17
France	201	0.15
United States	929	0.12
Republic of Korea	98	0.11
United Kingdom	72	0.11
Switzerland	77	0.10
Israel	20	0.10
Netherlands	51	0.10

3 years with significant patent publications. Among these assignee institutions, Japan Science and Technology Corp. is the second largest assignee institution with 48 patents and an average patent age of 2.29 years, which indicates its active role in recent nanotechnology development in the JPO.

Comparing the three tables, we observe that the top 20 assignee institutions are quite different among the three databases. However, those institutions the repositories have in common are important nanotechnology research institutions. For example, IBM, L’Oreal and Hitachi, Ltd. are in both the USPTO and JPO top 20 assignee lists. Eastman Kodak Co., Hewlett-Packard Development Company, L.P., and The Regents of the University of California are in both the USPTO and EPO top 20 assignee lists. These institutions have broader impact on nanotechnology research than other institutions that mainly publish in a single repository.

We find that most of the top assignee institutions in USPTO (Table 11) and JPO (Table 13) are from the United States and Japan, respectively. This phenomenon is an indication of “home advantage” at the assignee institution level. In the EPO (Table 12), European institutions do not dominate the top 20 list, but the list still hosts seven European companies: L’Oreal, BASF AG, Bayer AG, Centre National de la Recherche Scientifique (CNRS), Commissariat Energie Atomique, Institut für Neue Materialien, and Henkel KgaA. In general, the top 20 assignee institutions in the three repositories are mainly from the United States, Japan, France, Germany, and the Republic of Korea.

Table 11 Top 20 USPTO patent assignee institutions by number of patents published (“title-abstract” search, 1976–2004)

Rank	Assignee institution	Country	Number of patents	Average patent age
1	IBM	United States	171	6.65
2	The Regents of the University of California	United States	123	4.30
3	The United States of America as represented by the Secretary of the Navy	United States	82	5.15
4	Eastman Kodak Company	United States	72	7.19
5	Minnesota Mining and Manufacturing Company	United States	59	5.92
6	Massachusetts Institute of Technology	United States	56	3.61
7	Xerox Corporation	United States	55	4.71
8	Micron Technology, Inc.	United States	53	2.09
9	Matsushita Electric Industrial Co. Ltd.	Japan	45	6.89
10	L’Oreal	France	44	4.45
11	Texas Instruments, Incorporated	United States	41	5.44
12	Motorola, Inc.	United States	38	4.11
13	Advanced Micro Devices, Inc.	United States	35	2.17
14	General Electric Company	Japan	31	4.42
15	Kabushiki Kaisha Toshiba	United States	30	4.03
16	Allied Signal Inc.	Japan	28	3.29
17	California Institute of Technology	United States	27	2.52
18	Hewlett-Packard Development Company, L.P.	United States	27	0.30
19	Hitachi, Ltd.	Japan	27	6.96
20	Hyperion Catalysis International, Inc.	Japan	25	3.44

We inspected the patent publication trends since 1976 for the top 10 institutions (http://www.ai.arizona.edu/research/nanomapping/USPTOEPOJPO_Analysis.htm) to determine the relative productivity through time of each institution in the nanotechnology field.

- In the USPTO, several institutions had a steady increase in patent publication, such as The Regents of the University of California and the United States of America as represented by the Secretary of the Navy. Some institutions showed a decrease in recent years, e.g., IBM (decreased after 2001) and Micron Technology Inc. (decreased after 2001). Most assignee institutions started publishing nanotechnology patents in the 1990s, while IBM, The United States of America as represented by the Secretary of the Navy, Eastman Kodak Co., and Minnesota Mining and Manufacturing Company (3M Co.) started in the 1970s.
- In the EPO, Samsung Electronics Co. Ltd. had a sharp increase in the number of patents it published after 2001, while for most other insti-

tutions the number remained steady, such as L’Oreal and IBM. For some institutions, the number decreased, such as Eastman Kodak Co. and Japan Science and Technology Corp. Rohm and Haas published a great number of patents around 2003, which raised its position to third overall of the EPO assignee institutions.

- In JPO, many assignee institutions have experienced a decrease in recent years, such as Nippon Electric Co., Agency of Industrial Science and Technology, Tokyo Shibaura Electric Co., etc. However, Japan Science and Technology Corp. and National Institute for Materials Science continued to have active patent publications.

High-impact institutions

Tables 14 and 15 show the high-impact assignee institutions in the USPTO and EPO according to the average number of cites their patents received from other nanotechnology patents. Similar to what is

Table 12 Top 20 EPO patent assignee institutions by number of patents published (“title-abstract” search, 1978–2004)

Rank	Assignee institution	Country	Number of patents	Average patent age
1	L’Oreal	France	50	5.16
2	IBM	United States	44	11.91
3	Rohm & Haas	United States	41	3.41
4	Eastman Kodak Co.	United States	39	4.44
5	Samsung Electronics Co. Ltd.	Republic of Korea	28	0.75
6	Japan Science & Tech. Corp.	Japan	27	2.67
7	BASF AG	Germany	25	6.56
8	Matsushita Electric Ind Co. Ltd.	Japan	24	7.67
9	Allied Signal Inc.	United States	21	4.33
10	Lucent Technologies Inc.	United States	21	3.24
11	Japan Science & Tech. Agency	Japan	20	0.00
12	Bayer AG	Germany	19	5.11
13	Univ California	United States	19	4.89
14	Centre Nat Rech Scient	France	18	4.44
15	Commissariat Energie Atomique	France	18	3.06
16	Inst Neue Mat Gemein Gmbh	Germany	18	5.72
17	Henkel Kгаа	Germany	17	1.41
18	Hewlett Packard Co.	United States	17	2.94
19	Iljin Nanotech. Co. Ltd.	Republic of Korea	17	3.47
20	Samsung Sdi Co. Ltd.	Republic of Korea	17	2.24

Table 13 Top 20 JPO patent assignee institutions by number of patents published (“title-abstract” search, 1976–2004)

Rank	Assignee institution	Country	Number of patents	Average patent age
1	Nippon Electric Co.	Japan	103	7.17
2	Japan Science & Tech. Corp.	Japan	48	2.29
3	Agency Ind Science Techn	United States	43	6.21
4	Matsushita Electric Ind Co. Ltd.	Japan	43	9.07
5	Tokyo Shibaura Electric Co.	Japan	31	5.61
6	Sony Corp.	Japan	30	8.10
7	Canon Kk	Japan	28	8.75
8	Seiko Instr Inc.	Japan	26	8.35
9	Nat Inst for Materials Science	United States	25	1.00
10	Nat Inst of Adv Ind & Technol	Japan	24	1.25
11	Sharp Kk	Japan	24	4.79
12	Japan Res Dev Corp	Japan	22	9.00
13	Hitachi Ltd.	Japan	21	8.19
14	IBM	United States	21	8.05
15	Jeol Ltd.	Japan	21	9.19
16	L’Oreal	France	20	6.00
17	Nippon Telegraph & Telephone	Japan	19	7.32
18	Hitachi Metals Ltd.	Japan	13	7.54
19	Fujitsu Ltd.	Japan	12	8.75
20	Daiken Kagaku Kogyo Kk	Japan	11	3.36

Table 14 USPTO top 10 assignee institutions with more than 10 patents based on the average number of cites measure (“title-abstract” search, 1976–2004)

Assignee institution	Number of patents	Average number of cites
Digital Instruments, Inc.	24	9.42
AMCOL International Corporation	22	9.05
Agere Systems Guardian Corp.	11	9.00
Olympus Optical Co., Ltd.	15	7.47
Hyperion Catalysis International, Inc.	25	6.84
The Penn State Research Foundation	18	5.39
Allied Signal Inc.	28	5.21
The Board of Trustees of the Leland Stanford Junior University	21	5.14
President & Fellows of Harvard College	25	5.12
Nano Systems L.L.C.	10	4.40

Table 15 EPO top 10 assignee institutions with more than 10 patents based on the average number of cites measure (“title-abstract” search, 1978–2004)

Assignee institution	Number of patents	Average number of cites
Canon Kk	12	0.92
Lucent Technologies Inc	21	0.52
IBM	44	0.50
Hitachi Europ Ltd.	15	0.47
Hitachi Ltd.	15	0.40
L’Oreal	50	0.38
Matsushita Electric Ind Co. Ltd.	24	0.38
Rohm & Haas	41	0.37
Lee Cheol Jin	11	0.36
Max Planck Gesellschaft	10	0.30

observed in the high-impact countries, the average numbers of citations of the top assignees in the USPTO were larger than those of the top assignees in the EPO. The two tables we observe show that the suites of high-impact assignee institutions are quite different in the two repositories, indicating the different roles an institution may assume in different repositories.

Technology field analysis

In this research we use the third-level (subclass) IPC label to represent patent technology fields.

Table 16 shows the top 10 USPTO technology fields according to the number of patents published between 1976 and 2004. Technology field “H01L: Semiconductor devices; electric solid state devices not otherwise provided for” had the most nanotechnology patents published, almost double the amount of the second largest technology field “A61K: reparations for medical, dental, or toilet purposes.” The top technology fields in USPTO are mainly in biomedical research (e.g., technology fields A61K and C08K), material research (e.g., technology fields G01N, G01B, B32B, and B01D), and semiconductor research (e.g., technology fields H01L and H01J).

Table 17 shows the top 10 technology fields according to the number of patents published between 1978 and 2004 in the EPO. Here, no one field dominates, as does H01L in the USPTO. The top 10 technology fields in the EPO are mainly related to biomedical research (e.g., technology fields A61K, C01B, and C08K), chemistry research (e.g., technology fields B01J and C08L), material research (e.g., technology fields G01N, C01B, and B01D), and semiconductor research (e.g., technology fields H01L and H01J).

The top 10 technology fields in JPO patents according to the number of patents published between 1976 and 2004 are presented in Table 18. The top 10 technology fields in JPO are mainly related to biomedical research (e.g., technology fields A61K, C01B, and C23C), material research (e.g., technology fields G01B, G01N, and B82B), and semiconductor research (e.g., technology fields H01L, H01J).

Table 19 provides compares the top technology fields in the three databases. The three repositories have several top technology fields in common. For example, five technology fields appeared in all three repositories: “A61K: Preparations for medical, dental, or toilet purposes,” “H01L: Semiconductor devices; electric solid state devices,” “H01J: Electric discharge tubes or discharge lamps,” “G01B: Measuring length, thickness, or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours,” and “G01N: Investigating or analyzing materials by determining their chemical or physical properties.” The USPTO

Table 16 Top 10 USPTO technology fields according to the number of patents published (“title-abstract” search, 1976–2004)

IPC class	Class name	Number of patents
H01L	Semiconductor devices; electric solid state devices not otherwise provided for	748
A61K	Preparations for medical, dental, or toilet purposes	431
H01J	Electric discharge tubes or discharge lamps	364
B32B	Layered products, i.e., products built-up of strata of flat or non-flat, e.g., cellular or honeycomb	352
G01N	Investigating or analyzing materials by determining their chemical or physical properties	344
B05D	Performing operations transporting	211
C08K	Use of inorganic or non-macromolecular organic substances as compounding ingredients	182
G01B	Measuring length, thickness, or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours	169
G02B	Optical elements, systems, or apparatus	147
B01D	Separation	139

Table 17 Top 10 EPO technology fields according to the number of patents published (“title-abstract” search, 1978–2004)

IPC class	Class name	Number of patents
A61K	Preparations for medical, dental, or toilet purposes	347
H01L	Semiconductor devices; electric solid state devices not otherwise provided for	271
G01N	Investigating or analyzing materials by determining their chemical or physical properties	226
C01B	Non-metallic elements; compounds thereof	222
C08K	Use of inorganic or non-macromolecular organic substances as compounding ingredients	152
B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	141
H01J	Electric discharge tubes or discharge lamps	119
C08L	Compositions of macromolecular compounds	90
G01B	Measuring length, thickness, or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours	87
B01D	Separation	81

Table 18 Top 10 JPO technology fields according to the number of patents published (“title-abstract” search, 1976–2004)

IPC class	Class name	Number of patents
H01L	Semiconductor devices; electric solid state devices not otherwise provided for	210
C01B	Non-metallic elements compounds thereof	153
H01J	Electric discharge tubes or discharge lamps	135
G01B	Measuring length, thickness, or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours	121
G01N	Investigating or analyzing materials by determining their chemical or physical properties	120
B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	79
H01S	Devices using stimulated emission	56
B82B	Nano-structures manufacture or treatment thereof	51
A61K	Preparations for medical, dental, or toilet purposes	45
C23C	Coating metallic material coating material with metallic material surface treatment of metallic material by diffusion into the surface, by chemical conversion or substitution coating by vacuum evaporation, by sputtering, by ion implantation or by chemical vapor deposition, in general	45

Table 19 Top 10 technology fields in USPTO (1976–2004), EPO (1978–2004) and JPO (1976–2004) (“title-abstract” search)

Rank	USPTO		EPO		JPO	
	IPC class	Number of patents	IPC class	Number of patents	IPC class	Number of patents
1	H01L	748	A61K	347	H01L	210
2	A61K	431	H01L	271	C01B	153
3	H01J	364	G01N	226	H01J	135
4	B32B	352	C01B	222	G01B	121
5	G01N	344	C08K	152	G01N	120
6	B05D	211	B01J	141	B01J	79
7	C08K	182	H01J	119	H01S	56
8	G01B	169	C08L	90	B82B	51
9	G02B	147	G01B	87	A61K	45
10	B01D	139	B01D	81	C23C	45

and EPO have another two top technology fields in common: “B01D: Separation” and “C08K: Use of inorganic or non-macromolecular organic substances as compounding ingredients.” The EPO and JPO have another two top technology fields in common: “B01J: Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus” and “C01B: Non-metallic elements; compounds thereof.” Although the top 10 technology fields are very similar in the three repositories, their rankings (and number of patents published) have significant differences. This phenomenon indicates that although worldwide nanotechnology research has some common focus, different regions have their specific strengths in these technology fields.

We inspect the top 10 technology fields’ patent publication trends since 1976 in the three repositories (http://www.ai.arizona.edu/research/nanomapping/USPTOEPOJPO_Analysis.htm). Most of the top 10 technology fields in the USPTO published in increasing number of nanotechnology patents since 1976. Among these technology fields, “H01L: Semiconductor devices; electric solid state devices” experienced the most rapid growth. The yearly patent publications in “A61K: Preparations for medical, dental, or toilet purposes” stabilized after 1996, which is different from the other technology fields.

In EPO, the top 10 technology fields also show increasing numbers. After 2000, “A61K: Preparations for medical, dental, or toilet purposes,” “H01L: Semiconductor devices; electric solid state devices,” and “C01B: Non-metallic elements; compounds thereof” showed faster growth than the other tech-

nology fields. Unlike for the USPTO trends, technology field H01L did not perform significantly better than A61K and G01N. The number of patents published in technology field “G01B: Measuring length, thickness, or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours” was consistent in recent years.

In the JPO, many of the technology fields experienced a decrease in recent years, which is significantly different from the technology field patent publication trends in USPTO and EPO. However, technology field “C01B: Non-metallic elements; compounds thereof” had a steady growth in patent publication.

The analysis also reveals changes in the three technology fields that are common among the repositories. For example, in recent years, the research on H01L was getting stronger in the USPTO, while research on A61K was becoming stable. In the EPO, research on A61K and H01L kept increasing. In the JPO, patent filings in almost all fields were significantly reduced in recent years.

High-impact technology fields

Tables 20 and 21 show the high-impact technology fields in the USPTO and EPO respectively, according to the average number of cites received by the patents. The fields having the highest impact are quite different between the two repositories. However, technology fields “H01J: Electric discharge tubes or discharge lamps” and “G01B: Measuring

Table 20 USPTO top 10 technology fields with more than 10 patents based on the average number of cites measure (“title-abstract” search, 1976–2004)

IPC class	Class name	Number of patents	Average number of cites
D01F	Chemical features in the manufacture of artificial filaments, threads, fibres, bristles, or ribbons; apparatus specially adapted for the manufacture of carbon filaments	80	4.31
B29B	Preparation or pretreatment of the material to be shaped; making granules or preforms; recovery of plastics or other constituents of waste material containing plastics	12	3.58
H01J	Electric discharge tubes or discharge lamps	364	3.40
C01B	Non-metallic elements; compounds thereof	136	3.39
G01B	Measuring length, thickness, or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours	169	3.12
C25D	Processes for the electrolytic or electrophoretic production of coatings; electroforming	30	3.03
G01T	Measurement of nuclear or X-ray radiation	12	3.00
C08J	Working-up general processes of compounding after-treatment not covered by subclasses	71	2.79
C08K	Use of inorganic or non-macromolecular organic substances as compounding ingredients	182	2.76
B44C	Producing decorative effects; mosaics; tarsia work; paperhanging	35	2.57

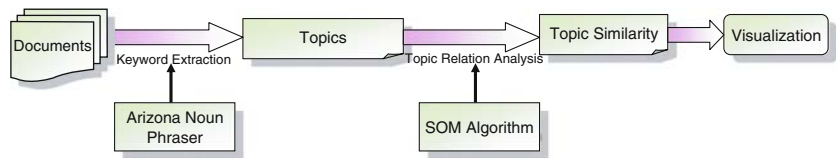
Table 21 EPO top 10 technology fields with more than 10 patents based on the average number of cites measure (“title-abstract” search, 1978–2004)

IPC class	Class name	Number of patents	Average number of cites
G01B	Measuring length, thickness, or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours	87	0.39
H01J	Electric discharge tubes or discharge lamps	119	0.37
G03C	Photography cinematography; analogous techniques using waves other than optical waves; electrography holography	19	0.32
G01R	Measuring electric variables measuring magnetic variables	17	0.29
B01F	Mixing, e.g., dissolving, emulsifying, dispersing	17	0.24
C09D	Coating compositions, e.g., paints, varnishes, lacquers, filling pastes, chemical paint or ink removers, inks, correcting fluids, woodstains, pastes or solids for coloring or printing; use of materials therefore	73	0.23
C09B	Organic dyes or closely related compounds for producing dyes; mordants; lakes	13	0.23
H01F	Magnets; inductances; transformers; selection of materials for their magnetic properties	51	0.20
G11B	Information storage based on relative movement between record carrier and transducer	57	0.18
A61K	Preparations for medical, dental, or toilet purposes	348	0.17

length, thickness, or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours” appear in both top 10 lists with large numbers of patents and high average numbers of citations. These two technology fields have broad impact in worldwide nanotechnology research. In general, the USPTO high-impact technology fields covered topics on material research (e.g., technology fields B29B and G01B), electrical engineering research (e.g., technology

fields H01J, C25D, and G01T), chemistry research (e.g., technology fields D01F and C08J), and biomedical research (e.g., technology fields C01B and C08K). The EPO high-impact technology fields covered topics on electrical engineering research (e.g., technology fields H01J and H01F), chemistry research (e.g., technology fields B01F, C09D and C09B), physics research (e.g., technology fields G03C and G01R), and biomedical research (e.g., technology field A61K).

Fig. 7 Content map analysis process



Content map analysis

In addition to using traditional bibliographic analysis methods to assess nanotechnology development, we also adopted content maps to visualize the major technology topics in the three repositories.

Figure 7 shows the process of generating a content map for a set of documents. Firstly, research topics, represented by keywords in the documents, are extracted using a natural language processing tool, the Arizona Noun Phraser, which can identify the key noun phrases based primarily on the linguistic patterns of free texts (Tolle and Chen 2000). Next, the topics are organized by the multi-level self-organization map algorithm (Chen et al. 1996; Ong et al. 2005) developed by the Arizona Artificial Intelligence Lab. This algorithm calculates the topic similarities according to the co-occurrence patterns of noun phrases in documents. The topics are positioned

geographically on a graph according to their similarities at the interfaces (see Figs. 8 and 9). The “topic map interface” contains two components: a folder tree and a hierarchical content map. On the left side, the folder tree displays related topics identified from the document. On the right side, the hierarchical content map displays corresponding topic regions. Conceptually, the closer the relationship is among the technology topics, the closer the geographic positions will be. The sizes of the topic regions are proportional to the number of documents assigned to the topics. The numbers of documents that were assigned to the different levels are presented in parentheses after the topic labels.

We generate a series of content maps of the three repositories for three time intervals: 1976(1978)–1989, 1990–1999, and 2000–2004. Each time interval’s content map is compared with the previous time interval’s content map to visualize the changes of

Fig. 8 USPTO content map (“title-abstract” search, 1976–1989)

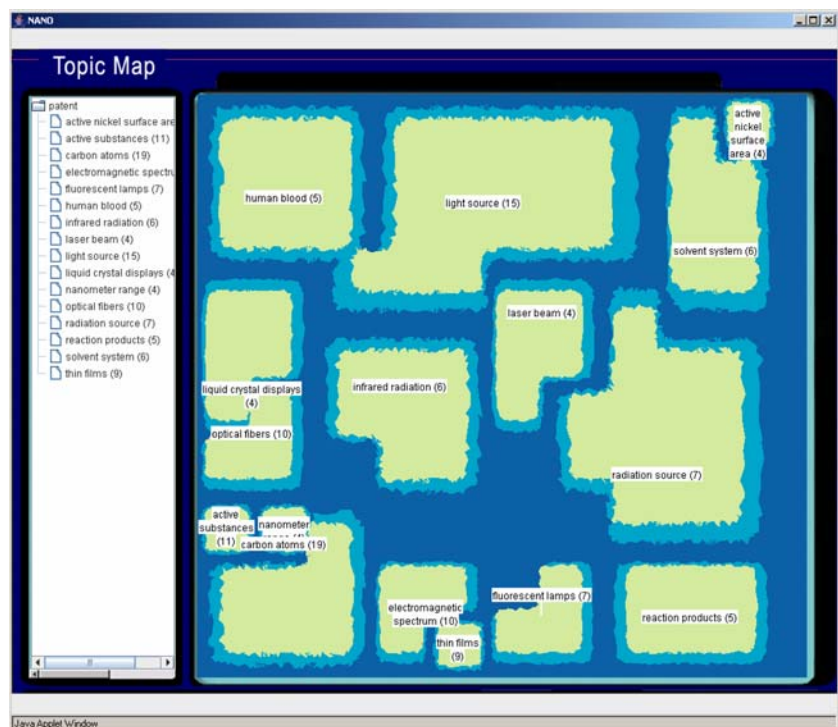
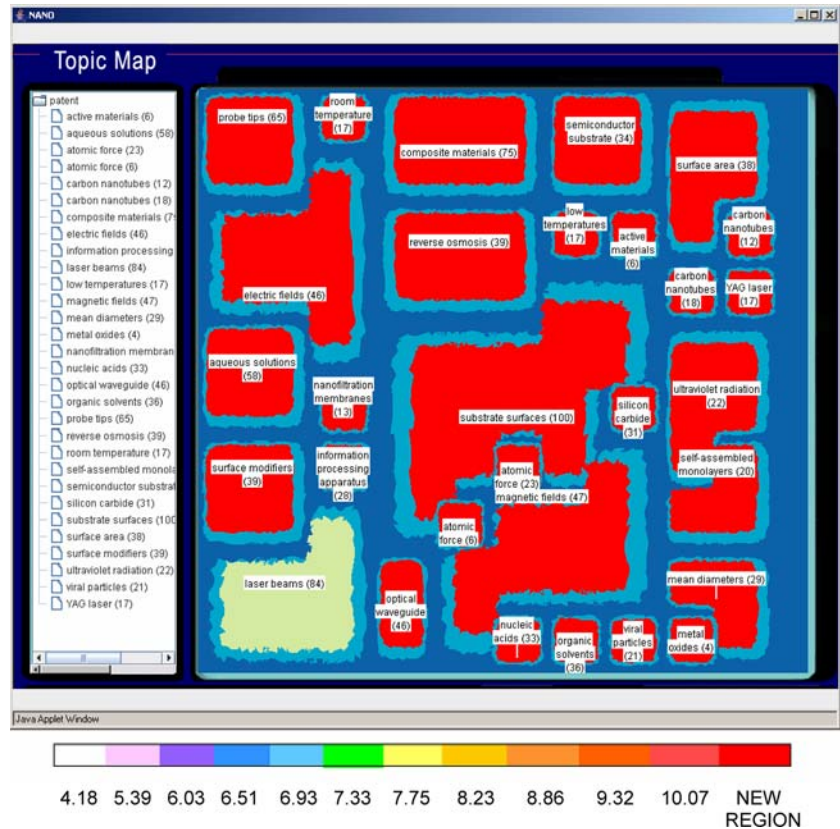


Fig. 9 USPTO content map (“title-abstract” search, 1990–1999). Baseline growth rate = 7.127



topic areas. For each topic area, a growth rate is computed as the ratio between the number of documents in the current time period and that of the previous time period. A baseline growth rate is computed as the ratio between the total number of documents in the current time period and that of the previous time period. A topic region with similar growth rate to the base growth rate is assigned a green color. A topic region with a higher or lower growth rate is assigned a warmer or colder color (to the left or right of green on the electromagnetic spectrum) respectively (see Fig. 9). If the topic is brand new, a red color is assigned to the region.

Content map analysis for 1976 (1978)–1989

Figure 8 presents the content map of USPTO nanotechnology patents published from 1976 to 1989. The major research topics in this time period included: “carbon atoms,” “optical fibers,” and “thin films.” The EPO and JPO had only 97 and 31 nanotechnology patents published from 1978 to 1989 and from

1976 to 1989, respectively. These repositories do not host enough nanotechnology patents to generate meaningful content maps for this time period.

Content map analysis for 1990–1999

Figure 9 illustrates the USPTO Content Map (using “title-abstract” search) for 1990–1999 (EPO and JPO’s content maps can be found at http://www.ai.arizona.edu/research/nanomapping/USPTOEOJPO_Contentmap.htm). The USPTO content map also shows the comparison between the topics in 1976–1989 and 1990–1999, on which the topic regions with higher or lower growth rates were assigned warmer or colder colors (the growth rate represented by each color is shown under the content map). Compared with the patents published between 1976 and 1989, the USPTO patents published between 1990 and 1999 have a baseline growth rate of 7.127 (Table 22), showing a significant increase of nanotechnology research in the USPTO in 1990s.

Table 22 Baseline growth rates for different time intervals at three repositories

Time period 1	Time period 2	Baseline growth rate
USPTO 1976–1989	USPTO 1990–1999	7.127
USPTO 1990–1999	USPTO 2000–2004	2.147
EPO 1990–1999	EPO 2000–2004	1.062
JPO 1990–1999	JPO 2000–2004	−0.382

- In the USPTO several new research topics appeared in the 1990s, including: “aqueous solutions,” “composite materials,” “laser beams,” “nucleic acids,” “optical waveguide,” “organic solvents,” “reverse osmosis,” “self-assembled monolayer,” “semiconductor substrate,” “silicon carbide,” and “substrate surfaces.”
- In the EPO, the major topics of nanotechnology patents in the 1990s were “aqueous solutions,” “atomic force,” “carbon nanotubes,” “magnetic core,” “metal oxides,” and “thin films.”
- In the JPO the major topics of nanotechnology patents in the 1990s were “atomic force microscope,” “laser beams,” “silicon substrate,” and “thin films.”

By comparing the three content maps, we observe that the USPTO had a broader coverage of nanotechnology topics than the other two databases during the 1990s.

Content map analysis for 2000–2004

We compared the content maps for 2000–2004 with those for 1990–1999 (http://www.ai.arizona.edu/research/nanomapping/USPTOEPOJPO_Contentmap.htm).

- In the USPTO, several topics had a significant increase in the numbers of patents published: such as “aqueous solutions,” “composite materials,” “carbon nanotubes,” “nucleic acids,” “self-assembled monolayer,” and “thin films.” Some new topics appeared, including “atomic force microscope,” “clay materials,” “dielectric layers,” “nanocomposite materials,” “naphtha stream,” “polymeric materials,” and “semiconductor devices.”
- In the EPO there was a significant increase in the topics “aqueous solutions,” “metal oxides,” and

“thin films.” New major topics included “gate electrode,” “low dielectric,” “nanocomposite materials,” “nanoparticulate compositions,” and “polymer compositions.”

- In the JPO, “atomic force microscope” and “thin films” remained major research topics. “Carbon nanofibers,” “gate electrodes,” “heat treatment” and “quantum dots” were the relatively new topics in that time period and attracted significant attention from both academe and industry.

Comparing with patents published between 1990 and 1999, the patents published between 2000 and 2004 had a growth rate of 2.147 in the USPTO, 1.062 in the EPO, and −0.382 in the JPO (Table 22). In the three repositories, the USPTO had a faster growth in nanotechnology patent publication than did EPO and JPO.

Comparison of topics across the three repositories

By comparing the three repositories’ nanotechnology patent content maps in different time spans, we find that the USPTO patents covered more topics than did the EPO and JPO. Many of the EPO and JPO topics were related to research tools and methods (e.g., “atomic force microscope,” “thin films,” and “scanning tunneling microscope”) and physics research (e.g., “carbon nanotubes,” “carbon nanofibers,” “low dielectric,” “magnetic core,” and “metal oxides”). Many USPTO topics were related to physics research (e.g., “carbon nanotubes,” “laser beams,” “optical waveguide,” and “self-assembled monolayer”), biomedical research (e.g., “nucleic acids,” “organic solvents,” “pharmaceutical compositions,” and “reverse osmosis”), and electronic research (e.g., “dielectric layers,” “semiconductor devices” and “semiconductor substrate”).

Citation network analysis

Citation networks (Figs. 11–15) describe connections between patents that cite other patents. In the citation networks graph, the direction of the links represents the direction of the citations. For example, a link from “Country A” to “Country B” means that Country A’s patents cited Country B’s patents and the number beside the link is the total number of citations. It allows us to identify the salient citation

patterns among countries, assignee institutions, and technology fields.

We outlined patent citation networks to explore knowledge diffusion in nanotechnology for countries, assignee institutions, and technology fields. We used the top 100 links between pairs of patents of each network (according to the number of citations between the patents) to create core networks for analysis. These citation networks are visualized using an open source graph visualization software, Graphviz, provided by AT&T Labs (Gansner 2000; available at: <http://www.research.att.com/sw/tools/graphviz/>).

Country citation network

Figure 10 displays the USPTO country citation network between 1976 and 2004. The United States is the most significant citation center on the network, which hosted patents cited and cited by those from many other countries. Japan, the Republic of Korea, the United Kingdom, China (Taiwan), and Germany are the secondary citation centers.

Figure 11 represents the EPO country citation network between 1978 and 2004. The United States, France, Japan, Germany, and the United Kingdom are large citation centers on the network.

Comparing the two citation networks in the USPTO and EPO shows that in both repositories the countries have close citation relationships, indicating effective knowledge diffusion in nanotechnology among countries. In the EPO, most countries have more than one country its patents cite or that cite its patents, indicating the complicated knowledge transfers between them. In the USPTO, several countries have a citation relationship only with the United States, while the others had complicated citation relationships. Many of the countries that only had citation connections with the United States were relatively new in the nanotechnology domain. The existence of these countries in the USPTO citation network, and their frequent citation of US patents, shows the crucial role the United States plays in the nanotechnology patents filed in the USPTO. It also shows the broader impact of USPTO patents on nanotechnology research in other countries.

Institution citation network

Figures 12 and 13 show the USPTO and EPO assignee institution citation networks. Both networks have several disconnected components. IBM, Massachusetts Institute of Technology, The Regents of

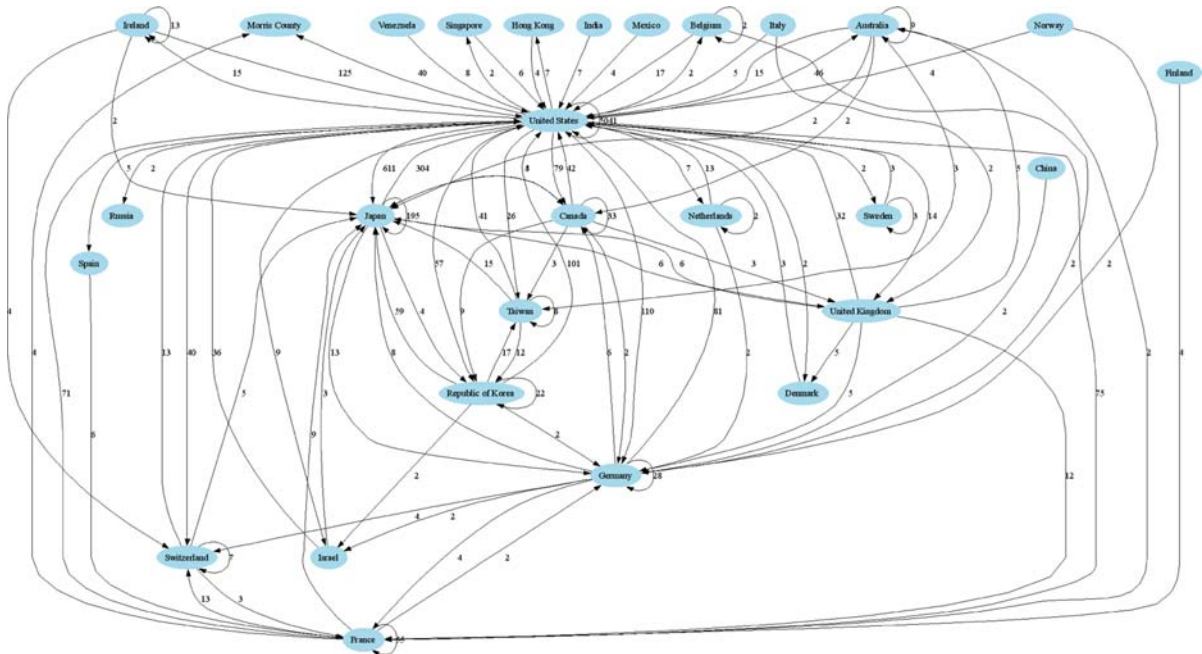


Fig. 10 USPTO country citation network (“title-abstract” search, 1976–2004)

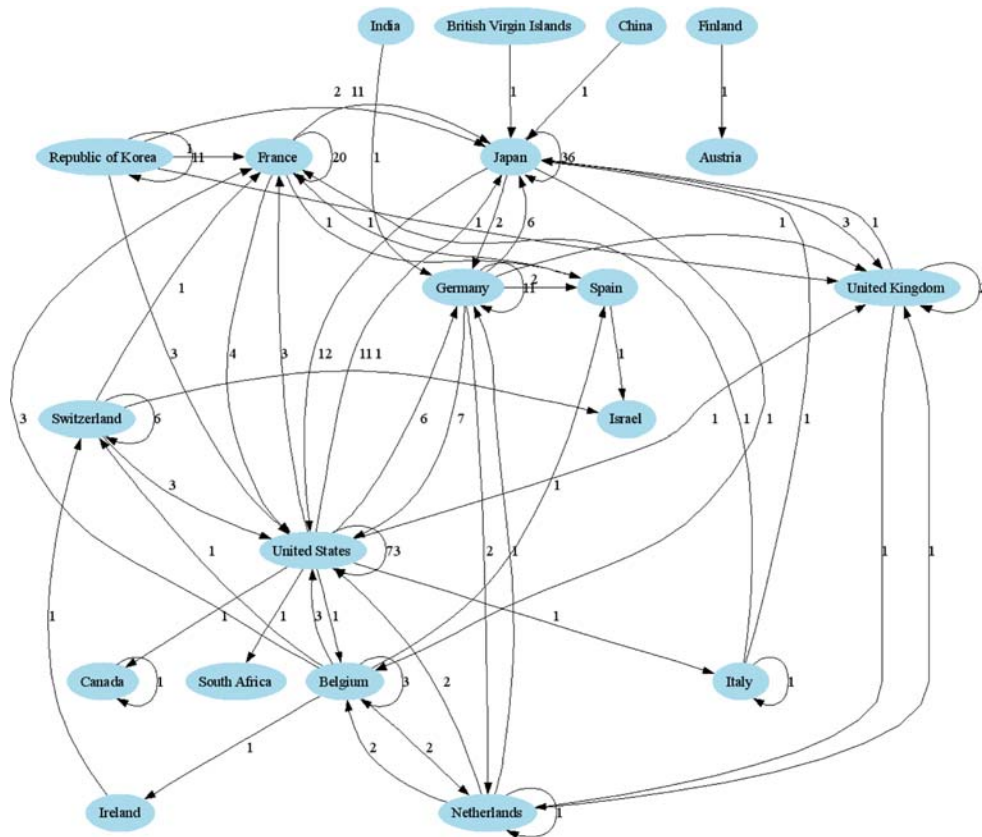


Fig. 11 EPO country citation network (“title-abstract” search, 1978–2004)

the University of California, and Molecular Imaging Corporation Co. (3M Co.) comprise the largest citation cluster in USPTO. This cluster contains both research companies and universities, which shows the close knowledge diffusion between academia and industry in the nanotechnology field.

The EPO hosts two main citation clusters. IBM, Hitachi Europe Ltd., Seiko Instruments Inc., Matsushita Electric Industrial Co. Ltd., etc. are the major citation centers in the first cluster. Lucent Technologies Inc., Iljin Nanotech Co. Ltd., Ise Electronics Corp., etc. make up the other large citation cluster. These two large citation clusters contain fewer universities than research companies.

Technology field citation network

The technology field citation networks in Figs. 14 and 15 show that both USPTO and EPO patents have close citation relationships within each depository.

The largest technology field citation centers in USPTO include “H01L: Semiconductor devices; electric solid state devices not otherwise provided for,” “G01N: Investigating or analyzing materials by determining their chemical or physical properties,” “B32B: Layered products, i.e., products built-up of strata of flat or non-flat, e.g., cellular or honeycomb, form,” and “H01J: Electric discharge tubes or discharge lamps.”

The major citation centers in the technology field citation network in EPO are: “H01J: Electric discharge tubes or discharge lamps,” “C08K: Use of inorganic or non-macromolecular organic substances as compounding ingredients,” “C09D: Coating compositions, e.g., paints, varnishes, lacquers; filling pastes; chemical paint or ink removers; inks; correcting fluids; woodstains; pastes or solids for coloring or printing; use of materials therefore,” and “C01B: Non-metallic elements; compounds thereof.”

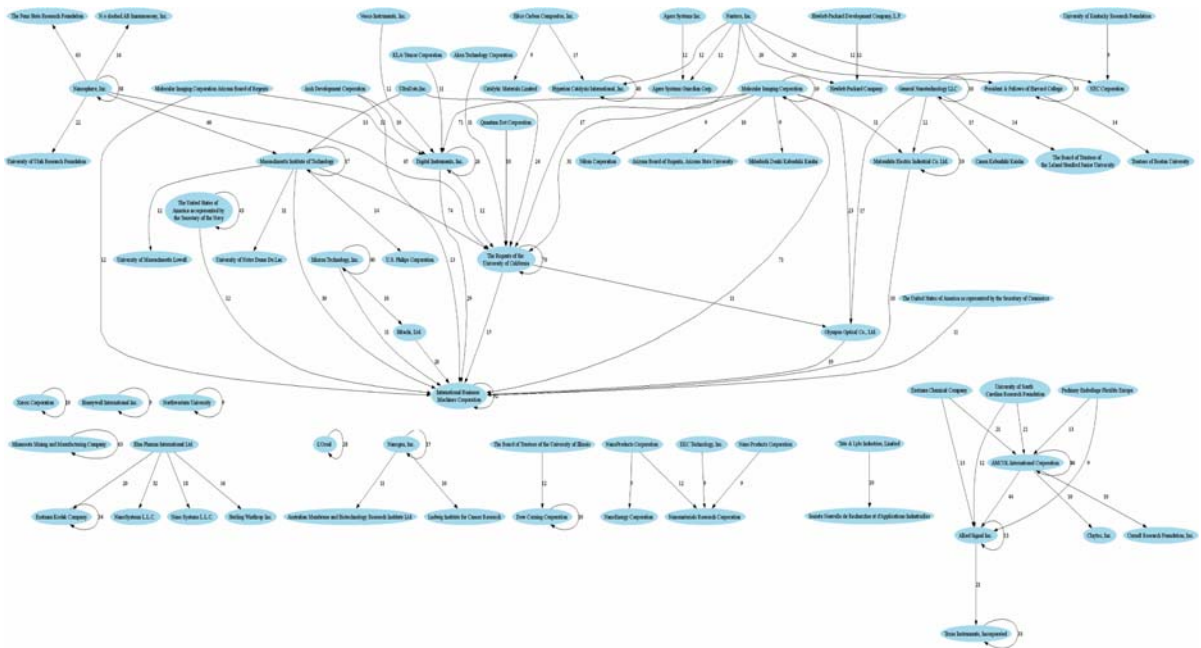


Fig. 12 USPTO institution citation network (“title-abstract” search, 1976–2004)

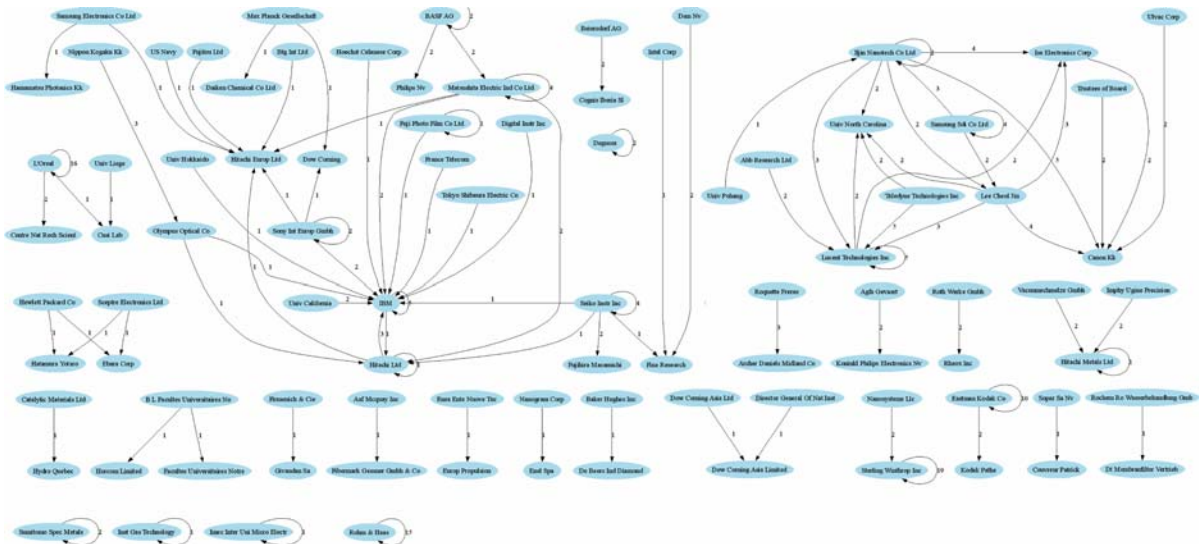


Fig. 13 EPO institution citation network (“title-abstract” search, 1978–2004)

Comparing the two citation networks, we find that in the USPTO, a major citation center usually has citation relationships with several smaller citation centers, forming a tree-like graph. On the other hand, in the EPO, most citation relations are between the major

citation centers. The USPTO citation network shows a clear pattern of knowledge diffusion from the major citation centers to the smaller citation centers. The EPO citation network shows a clear pattern of knowledge exchange among the major citation centers.

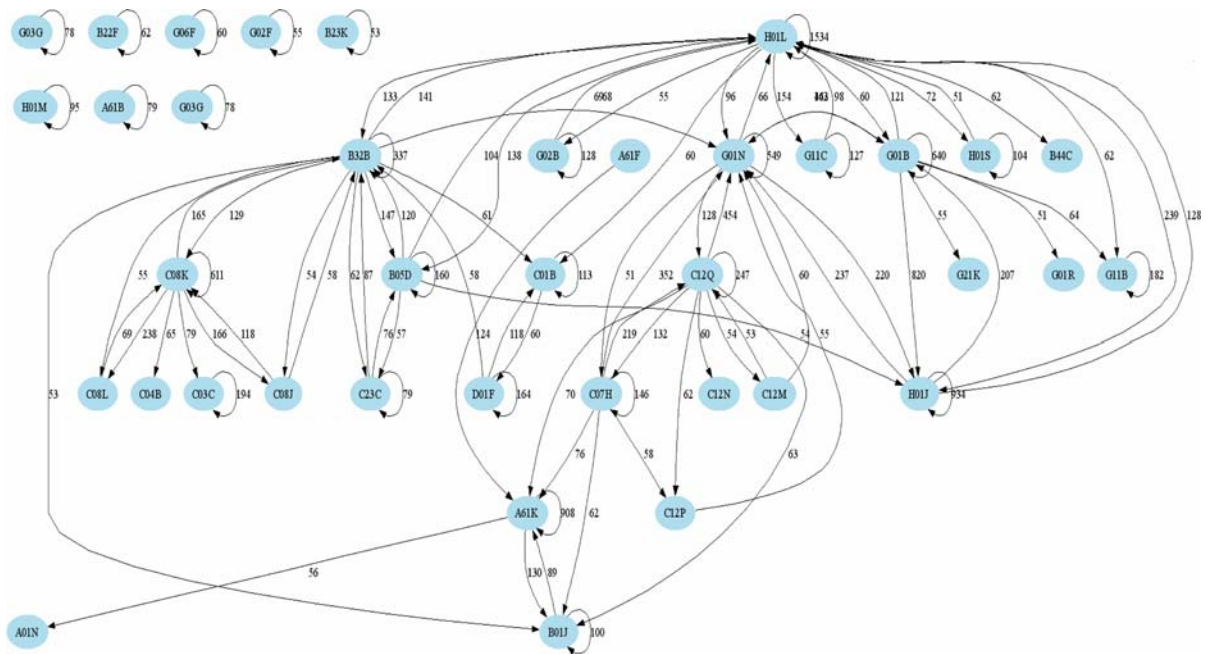


Fig. 14 USPTO technology field citation network (“title-abstract” search, 1976–2004)

Conclusions

The nanotechnology patents published in three repositories, the USPTO (1976–2004), EPO (1978–2004), and JPO (1976–2004), have been collected, parsed, and analyzed to assess nanotechnology’s worldwide research and development status. We have conducted three types of analyses (bibliographic, content map, and citation network) for countries, institutions, and technology fields. The three patent repositories have differences in their patent development trends, research topics, and knowledge diffusion processes.

Key findings of our analyses are:

- The nanotechnology patents issued by both the USPTO and EPO experienced quasi-exponential growth in the past 30 years. The nanotechnology patents issued by the JPO followed the same trend until stabilizing after 1993.
- In the USPTO and EPO, the high productivity assignee countries and their rankings are very similar to each other. In both repositories, the United States filed the most nanotechnology patents. The patent publication ranking of some of the top assignee countries, e.g., France, are different in the two repositories.
- The number of nanotechnology patents published by the four country groups (United States, European Group, Japan, and Others) increased in both the USPTO and EPO. The United States filed significantly more nanotechnology patents than the other three groups in the USPTO, while it filed a similar number of patents as European countries in EPO.
- The high-impact assignee countries (according to the average number of cites their patents received) are quite different in the USPTO and EPO. However, the United States and Japan published larger numbers of the patents with high citation averages in both repositories, indicating their important roles in international nanotechnology development.
- The top assignee institutions according to the number of patents published are significantly different among the USPTO, EPO, and JPO databases. However, IBM and L’Oreal are high-productivity assignee institutions that appear in all three repositories’ top lists. Most of the top assignees in the USPTO and JPO are US and Japanese institutions, respectively. The number of patents published by top JPO assignee institutions decreased in recent years, a pattern not seen in the

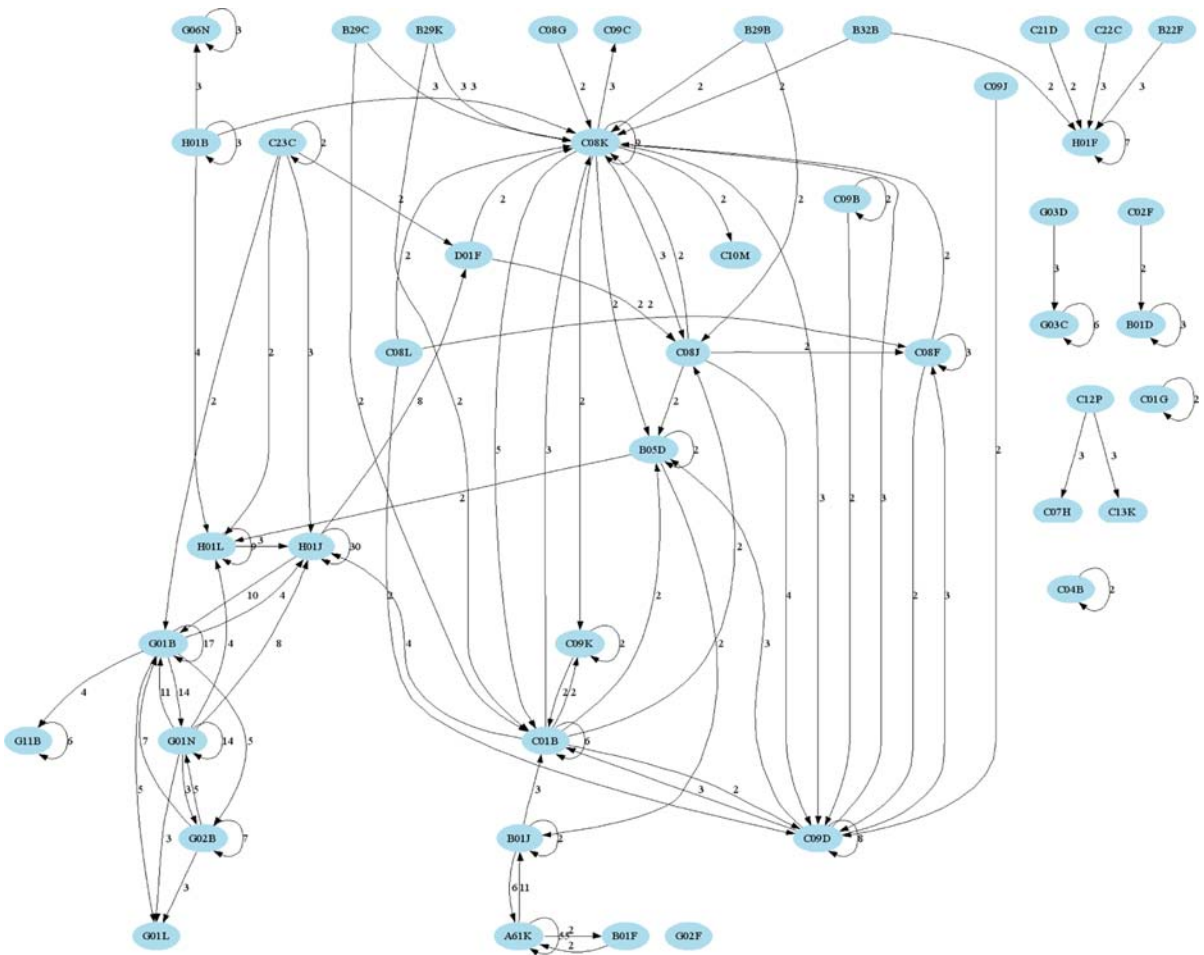


Fig. 15 EPO technology field citation network (“title-abstract” search, 1978–2004)

USPTO and EPO. (The drop in the number of JPO patents in the last 2 years is due to the delay of patent registration after publication, a problem unique to JPO.)

- The USPTO, EPO, and JPO have many high-productivity technology fields (represented by IPC third-level classification categories) in common. But the rankings of these technology fields are quite different.
- Overall, the USPTO and EPO have different technology fields with high impact, as determined by average number of cites. However, several technology fields such as “H01J: Electric discharge tubes or discharge lamps” and “G01B: Measuring length, thickness, or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours”

had large numbers of patents and high average numbers of citations in both repositories.

- The content map analysis showed that USPTO patents cover more technology topic areas than EPO and JPO patents. Many of the USPTO research topics were related to physics research, biomedical research, and electronics research. Many of the EPO and JPO topics were related to research tools and methods and physics.
- The assignee countries had close citation relationships in both USPTO and EPO country citation networks. In both networks, the United States was an important citation center. The USPTO patents, particularly the US patents in the USPTO, had broader impact on worldwide nanotechnology development and attracted more citations from other countries than did EPO patents.

- Both the USPTO and EPO assignee institution citation networks revealed several disconnected components. IBM was an important citation center in both repositories. Compared with the EPO, the USPTO had more citations between research companies and universities.
- The technology fields have good citation relationships in both the USPTO and EPO. The USPTO technology field citation network shows a clear pattern of knowledge diffusion from the major citation centers to the smaller citation centers. The EPO technology field citation network shows a clear pattern of knowledge exchange among the major citation centers.

Future research will include the collaboration pattern of inventors in the three repositories to determine the relationship between collaboration and patent productivity, as well as the impact of patents in nanotechnology research. Also, we plan to extend our research framework to include other international patent offices documents, such as those in Germany, the People's Republic of China, South Korea, and France.

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