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PERSPECTIVES

Trends in worldwide nanotechnology patent applications: 1991 to 2008

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Abstract Nanotechnology patent applications published during 1991–2008 have been examined using the "title–abstract" keyword search on *esp@cenet* "worldwide" database. The longitudinal evolution of the number of patent applications, their topics, and their respective patent families have been evaluated for 15 national patent offices covering 98% of the total global activity. The patent offices of the United States (USA), People's Republic of China (PRC), Japan, and South Korea have published the largest number of nanotechnology patent applications, and experienced significant but different growth rates after 2000. In most repositories, the largest numbers of nanotechnology patent applications originated from their own countries/regions, indicating a significant "home advantage." The top applicant institutions are from different sectors in different countries (e.g., from industry in the US and Canada patent offices, and from academe or government agencies at the PRC office). As compared to 2000, the year before the establishment of the US National Nanotechnology Initiative (NNI), numerous new invention topics appeared in 2008, in all 15 patent repositories. This is more pronounced in the USA and PRC. Patent families have increased among the 15 patent offices, particularly after 2005. Overlapping patent applications increased from none in 1991 to about 4% in 2000 and to about 27% in 2008. The largest share of equivalent nanotechnology patent applications (1,258) between two repositories was identified between the US and Japan patent offices.

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Introduction

Nanotechnology developments continue to be produced at exponential rates for a wide and diverse range of applications. Because of nanotechnology's pivotal role in future scientific and economic development, in order to remain competitive, more than 60 countries have adopted national projects or programs to prompt research in nanotechnology since 2000 (Roco 2005). Patent analysis is an indicator for assessing development of different research communities and technology fields (Narin 1998; Oppenheim 2000). Our evaluation framework integrates bibliographic, citation (Garfield 1955), contents (Tolle and Chen 2000), network (Albert and Barabasi 2002), and statistical analyses. The framework has been applied to nanotechnology patent publications in the US Patent and Trademark Office (USPTO), the European Patent Office (EPO), and the Japan Patent Office (JPO) in Huang et al. (2003) (for USPTO), Huang et al. (2006) (for USPTO), and Li et al. (2007) (for USPTO, EPO, and JPO).

This study has considered all the public repositories and is focused on data from the 15 countries'/regions' repositories that are most active in the nanotechnology domain; these repositories cover 98% of the patent applications worldwide. The respective applications were searched on titles and abstracts ("title–abstract" search) using a group of keywords provided by domain experts (Huang et al. 2003). This article presents the longitudinal evolution of the number of patent applications after their origin, topics, and corresponding patent families since 1991.

Analysis method of patent applications

Data collection and preprocessing

Nanotechnology publications from different countries'/regions' patent offices (repositories) were extracted from the *esp@cenet* "worldwide" database into our database by using keyword "title–abstract" searching.

A patent office is a governmental or intergovernmental organization which controls the issue of patents. Different countries have their own patent offices, such as the USPTO, the JPO, the Canadian Intellectual Property Office (CIPO), and the South Korean Intellectual Property Office (KIPO). In addition to national (country level) patent offices, there are several regional (country group level) patent offices as well, such as the EPO and the World Intellectual Property Organization (WIPO). The EPO grants European patents for the 27 member states of the European Patent Convention. The WIPO is a specialized agency of the United Nations with 184 member states in 2008. It grants patents for all of its member states. Many countries publish patent applications and/or grant patent rights for public information (Chemical Abstracts Service 2008).

A reliable international database covering patent information from multiple patent offices is the *esp@cenet* "worldwide" database, which is maintained by the EPO together with the member states of the European Patent Organization. *Esp@cenet* includes three databases:

– "EPO" database
– "WIPO" database
– "worldwide" database

The esp@cenet "worldwide" database contains the patent applications examined and published by 85 individual countries'/regions' patent offices, including the USPTO, EPO, and JPO. The *esp@cenet* "worldwide" database holds more than *60 million patents* (Espacenet Website, "Coverage of the worldwide database") (Espacenet Website, "Coverage of the worldwide database") (EPO 2008). English translations for all other languages are provided for the bibliographic information, and selected content information (such as abstract, claim, and description) are also provided. Owing to the limitation of the search functions of *esp@cenet*, we collected the patent applications by searching the nanotechnology keywords only in each patent application's title and abstract ("title–abstract" search).

The *esp@cenet* "worldwide" database previously has been used to examine patents in biology (Oldham and Cutter 2006), hydrogen and fuel cells (Seymour et al. 2007), and globalization of knowledge (Andersen et al. 2006).

Patent parsing

Two sets of patent information were parsed into our database from the collected patent applications:

– Nanotechnology patent applications published in different countries'/regions' patent offices (repositories)
– Patent family information of these patent applications.

Table 1 shows the data field limitation of our patent application collection. Most of the data fields are available in the *esp@cenet* "worldwide" database.

Table 1 Data field limitation of the *esp@cenet* “worldwide” database

Data field	Available
Publication number	Yes
Publication date	Yes
Inventor name	Yes
Applicant institution name	Yes
Applicant country	*
International patent classification code (IPC)	Yes
European patent classification code (EPC)	*
Citation information	No
Priority number(s)	Yes
Title	Yes
Abstract	Yes
Claim	*
Description	*

* The patent application data from some countries/regions’ patent offices is incomplete

However, it does not contain the citation information for patent applications published in patent offices other than EPO and WIPO (Espacenet Website, “What is a cited document?”). For some regional or country patent offices, the bibliographic data (such as the application country, European patent classification code (EPC), claim, or description) are incomplete. All the selected repositories in our study are part of EPO and WIPO.

A patent application for an invention is originally filed in one country; however, it can be filed later in other countries as well. The original, first application filing generally is considered to be the priority application (Hingley and Park 2003). In *esp@cenet*, such related applications or “members of corresponding documents” or “equivalents” and have exactly the same priority (Espacenet Website, “Also published as documents”).

A *patent family* is a group of patents that are all related to each other. We use the *esp@cenet* patent “simple family” definition as comprising all the documents having exactly the same priority or combination of priorities (Espacenet Website, “Patent families”). The International Patent Documentation Center (INPADOC) defines as “expanded family” all the documents sharing directly or indirectly (e.g., via a third document) at least one priority (Espacenet Website, “Patent families”).

Data analysis

Three types of analyses were conducted using the data collected from the previous components:

- Longitudinal evolution of the number of patent publications per year and per applicant (i.e., the institution to which a patent is assigned to countries, applicant institutions, and technology fields)
- Topic analysis, where we have created content maps to identify the most important and emerging research topics in nanotechnology domain in different time intervals for each patent office (repository).
- Patent family analysis across different patent offices (repositories) including ranking those with the largest numbers of equivalent patent applications.

Results

Data description

We collected the nanotechnology patent applications published from 1991 to 2008 from the *esp@cenet* “worldwide” database. We focused attention on the leading 15 country/regional patent offices that cover *more than 98% of the whole collection;* each has more than 100 patent applications.

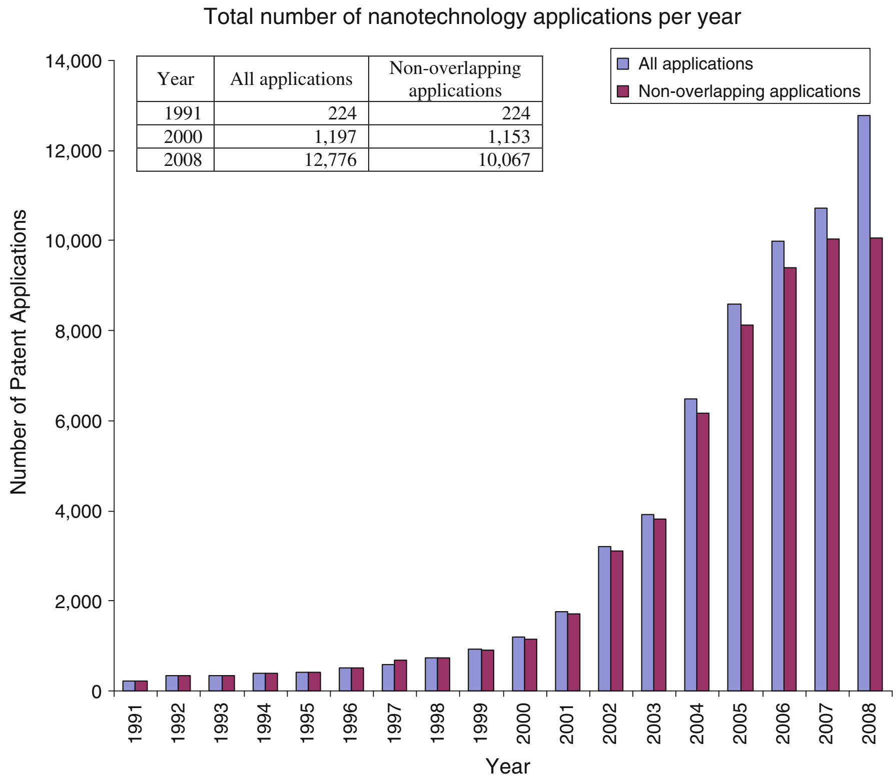
Longitudinal evolution of patent applications

Global increase of nanotechnology patents

The evolution of the total number of nanotechnology patent applications in the 15 repositories per year from 1991 to 2008 is shown in Fig 1. This figure also shows the number of non-overlapping nanotechnology patent applications by considering one patent application per family. The annual rate of increase for all the patent publications is more pronounced between 2000 and 2008 (34.5%). This rate is higher than that of Science Citation Index’s article publication rate of 20–25% for the same period when we use the same keyword “title–abstract” search approach as for patent applications.

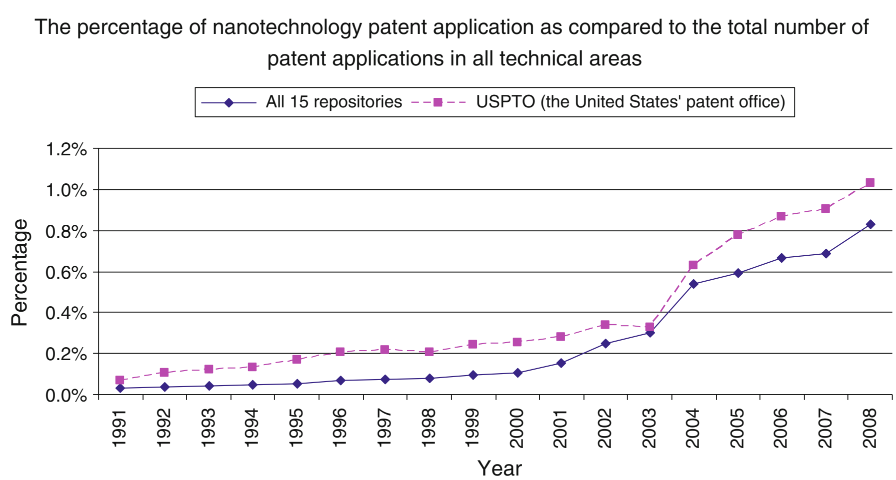
The percentage of nanotechnology patent application as compared to the total number of patent applications in all the technical areas is illustrated in Fig. 2.

Fig. 1 Longitudinal evolution of the total number of nanotechnology patent applications in the 15 repositories per year ("title abstract," 1991–2008)



Year	All applications	Non-overlapping applications
1991	224	224
2000	1,197	1,153
2008	12,776	10,067

Fig. 2 Longitudinal evolution of the percentage of patent publications on nanotechnology versus all topics, in the repositories of leading 15 countries/regions and USA from 1991 to 2008 using keyword "title–abstract" search



The nanotechnology patent application percentages for the USPTO reported in the above figure are consistent with the data trends reported in previous studies (Huang et al. 2006; Hu et al. 2007) where the granted patents were searched by "title–claims" from 1991 to 2004. In that study, the percentage of granted patents reached 1.09% in 2004 versus 0.63% for patent applications in Fig. 2. Our previous studies also showed that the nanotechnology-granted patent percentages for "full-text" search was 4.85% in 2004 for the USPTO.

Number of patent applications per repository

Table 2 lists the numbers of nanotechnology patent applications published by each of the 15 countries/

Table 2 Nanotechnology patent applications published in the top 15 countries/regions' patent offices in the interval 1991 to 2008 using keyword "title–abstract" search

Rank	Patent office (repository)	No. of nanotechnology patent applications (1991–2008)	2000	2008
1	USA	19,665	405	3,729
2	PRC	18,438	105	5,030
3	Japan	10,763	328	1,744
4	South Korea	5,963	74	1,249
5	Canada	1,539	41	255
6	Taiwan	1,363	28	3
7	Germany	1,312	62	70
8	Australia	1,296	76	136
9	Russian Federation	859	45	162
10	Mexico	471	0	88
11	UK	412	14	68
12	France	390	8	38
13	Brazil	315	0	103
14	Ukraine	243	0	83
15	New Zealand	140	11	18

regions' patent offices from 1991 to 2008. The USPTO examined and published the largest number of nanotechnology patent applications, followed by the patent offices of the PRC and Japan.

The total number of nanotechnology patent applications published from 1991 to 2008 by authors from the US and PRC are estimated each at over 17,000. Over 20% of the US patent applications and 4% of the PRC's are in foreign repositories.

Figures 3 and 4 show the evolution of the numbers of nanotechnology patent applications published in different countries'/regions' patent offices by year. Since the patent offices of the US, PRC, Japan, and South Korea had many more nanotechnology patent applications, we present their evolution trends in Fig. 3. The evolution trends of the other 11 countries'/regions' patent offices are shown in Fig. 4.

The patent offices of the US, PRC, Japan, and South Korea have significantly more nanotechnology patent applications than other patent offices, and all experienced larger increases especially after 2003. The PRC's repository surpassed the USA' repository after 2006. As shown in Fig. 4, the other 11 patent offices have experienced mostly increases but also decreased in recent years. The patent offices of the Russian Federation, Brazil, and the United Kingdom (UK) reached their peaks in 2008 with 162, 103, and 68 nanotechnology patent applications, respectively. The Ukraine's patent office peaked in 2007 with 87

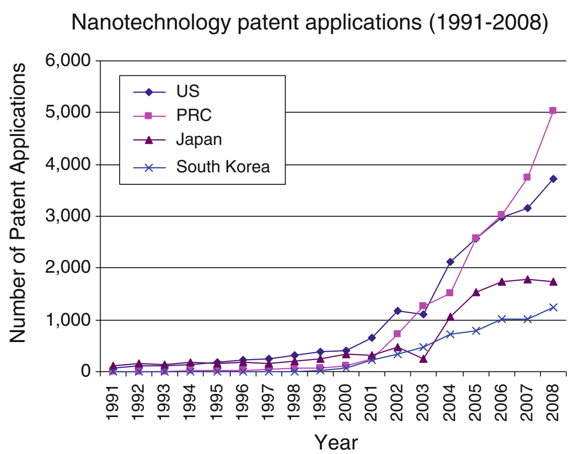
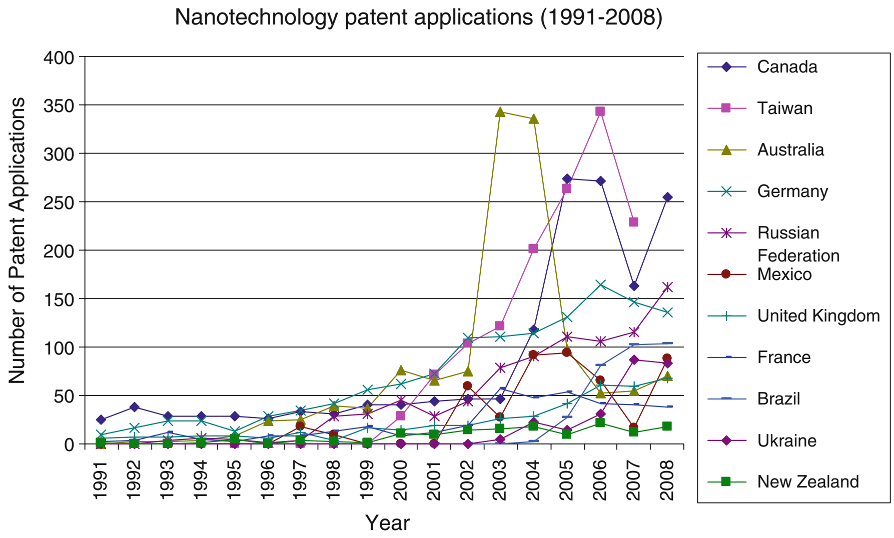


Fig. 3 The numbers of nanotechnology patent applications from all countries in the patent offices of the US, PRC, Japan, and South Korea using "title–abstract" search, from 1991 to 2008

nanotechnology patent applications, and the patent offices of Germany and New Zealand reached their peaks in 2006 with 164 and 21 nanotechnology patent applications, respectively. Canada's and Mexico's patent offices reached their peaks in 2005 with 274 and 94 nanotechnology patent applications, respectively. Australia's and France's patent offices peaked in 2003 with 343 and 57 nanotechnology patent applications, respectively. Taiwan's patent office had more than 200 nanotechnology patent applications per year from

Fig. 4 The numbers of nanotechnology patent applications from all the countries in the remaining 11 patent offices using "title–abstract" search from 1991 to 2008



2004 to 2007 with 2006 as the peak (343 applications); however, the number dropped dramatically in 2008 to only three nanotechnology patent applications probably due to a delay in collecting the 2008 Taiwan patent data by the *esp@cenet* "worldwide" database. In all following analyses, we used 2007 data for Taiwan's patent office instead of 2008.

Most patent offices generally publish the country of origin of the patent publications, with the exceptions of Japan, Australia, and New Zealand. Table 3 lists the top five countries where patent applications were filled from 1991 to 2008. For several of the other patent offices, a small portion of their patent applications may have incomplete applicant country information. In these cases, we manually verified the information. For each application having the applicant same as the inventor(s), we then used the country of the first inventor as its applicant country. As a comparison, we also list the numbers of nanotechnology patent applications published in 2000 (the year before the establishment of the US National Nanotechnology Initiative; Roco et al. 2000) and 2008 (the most recent year with data available for the whole year).

The USA was the most active internationally with the largest numbers of nanotechnology patent applicants published in other patent offices. It ranked first in three out of the 12 patent offices, including its own patent office, Canada's, and Mexico's patent offices; it ranked second in the patent offices of six other countries; and third in the remaining three patent offices. Japan, Germany, South Korea, and France are the most active internationally after the USA.

These results on country ranking generally are consistent with those reported in the previous study on granted patents at USPTO using "title–claims" search (Li et al. 2007), in which study the top five applicant countries of USPTO nanotechnology-granted patents published from 1976 to 2004 were the US (3,450 patents), Japan (517 patents), Germany (204 patents), France (156 patents), and South Korea (131 patents), with Taiwan being the seventh. In this study, the top five applicant countries identified were the US, Japan, South Korea, Germany, and Taiwan. However, the numbers of nanotechnology patent documents reported in this study are different from those reported by Li et al. (2007) due to three reasons. First, instead of using the granted patents as used by Li et al. (2007), we used the published patent applications as the data source in this study, because the *esp@cenet* "worldwide" database does not differentiate granted patents from published patent applications. Second, in this study involving 15 repositories we could not use the more complete "title/abstract/claims" used in previous study only for the USPTO. Third, our results are based on the data published from 1991 to 2008 while the numbers reported by Li et al. (2007) are based on the data published from 1976 to 2004. Many patent offices have published a large number of nanotechnology patents in recent years.

Table 3 shows that all the patent offices except those of Canada and Mexico had the largest numbers of nanotechnology patent applications published by applicants from their own countries. This indicates a "home advantage" effect. As defined in previous

Table 3 Top five applicant countries in 12 countries/regions' patent offices based on the number of nanotechnology patent applications from 1991 to 2008

No.	Patent office/repository (no. of applications from all countries)	Rank	Applicant country	Number of nanotechnology patent applications (1991–2008)	2000	2008
1	USA (19,665)	1	USA	12,606	285	2,288
		2	Japan	1,866	42	308
		3	South Korea	1,272	6	343
		4	Germany	1,048	23	168
		5	Taiwan	839	7	175
2	PRC (18,438)	1	PRC	16,348	85	4,409
		2	USA	805	3	260
		3	South Korea	327	5	80
		4	Japan	301	2	64
		5	Germany	145	3	43
3	South Korea (5,963)	1	South Korea	4,087	41	967
		2	USA	461	15	151
		3	PRC	145	1	53
		4	Japan	138	4	39
		5	Germany	119	0	42
4	Canada (1,539)	1	USA	825	18	156
		2	Canada	192	4	28
		3	Germany	124	7	18
		4	France	57	6	7
		5	Japan	53	2	5
5	Taiwan (1,363)[a]	1	Taiwan	906	3	165
		2	USA	224	17	26
		3	Japan	113	3	17
		4	Germany	35	3	6
		5	South Korea	32	2	10
6	Germany (1,312)	1	Germany	1,182	56	124
		2	Taiwan	21	1	1
		3	USA	20	1	3
		4	South Korea	16	2	2
		5	Japan	15	0	1
7	Russian Federation (859)	1	Russian Federation	711	41	147
		2	USA	37	1	3
		3	Japan	17	0	3
		3	Germany	17	1	1
		5	France	16	0	2
8	Mexico (471)	1	USA	277	0	53
		2	Germany	30	0	5
		3	Mexico	28	0	4
		4	France	26	0	3
		5	Switzerland	20	0	2

Table 3 continued

No.	Patent office/repository (no. of applications from all countries)	Rank	Applicant country	Number of nanotechnology patent applications (1991–2008)	2000	2008
9	UK (412)	1	UK	162	5	27
		2	USA	109	8	15
		3	Germany	25	0	7
		4	Japan	20	0	3
		5	South Korea	19	1	5
10	France (390)	1	France	358	6	37
		2	Belgium	6	0	2
		2	Japan	6	0	0
		4	Taiwan	5	0	0
		4	USA	5	2	0
11	Brazil (315)	1	Brazil	116	0	42
		2	USA	99	0	32
		3	Germany	25	0	8
		4	Switzerland	21	0	4
		5	France	15	0	5
12	Ukraine (243)	1	Ukraine	221	0	78
		2	Switzerland	4	0	3
		3	Japan	2	0	0
		4	Switzerland	1	0	0
		4	USA	1	0	0

[a] As noted previously, data from 2007 was used for Taiwan's patent office, rather than 2008

studies, the "home advantage" effect is the tendency of domestic applicants to file more patents with their home country patent office than foreign applicants (European Commission 1997; Ganguli 1998; Criscuolo 2005).

By comparing the numbers of nanotechnology patent applications published in 2000 and 2008, the tremendous increase in nanotechnology patent applications from each top applicant country can be easily perceived. Especially notable are the increases recorded by Mexico, Brazil, and Ukraine.

Top applicant institutions

Table 4 lists the leading five applicant institutions per repository that includes large companies, universities, and research centers. In each of the patent offices of the PRC, South Korea, Germany, Russian Federation, France, and Ukraine, all of the top five applicant institutions were from the home country. In contrast, all the top five applicant institutions in Australia's patent office came from the USA. Four out of the top five application institutions in both Canada's and Mexico's patent offices were from the USA. In addition, none of the top five applicant institutions in New Zealand's patent office was from its home country. Some internationally active applicant institutions that ranked among the top five in different countries'/regions' patent offices included IBM (from the US), the University of California (from the USA), Samsung Electronics Co. Ltd. (South Korea), Hon Hai Prec Ind Co. Ltd. (Taiwan), Industrial Technology Research Institute (Ind Tech Res Inst; Taiwan), Hyperion Catalysis International Inc. (USA), and General Electric (USA).

In the USA's patent office, IBM ranked first, followed by the University of California and Samsung Electronic Co. In Japan's patent office, the National Institute for Materials Science (Nat Inst for Materials Science) ranked first followed by the National Institute of Advanced Industrial Science and Technology (Nat Inst of Adv Ind & Technol) and Matsushita

Table 4 Top five applicant institutions in the 15 patent offices based on the number of nanotechnology patent applications from 1991 to 2008

No.	Patent office/ repository	Rank	Applicant institution	Country of the institution	Number of nanotechnology patent applications (1991–2008)	2000	2008
1	USA	1	IBM	USA	277	11	54
		2	Univ California	USA	209	11	29
		3	Samsung Electronics Co. Ltd.	South Korea	172	0	69
		4	Hon Hai Prec Ind Co. Ltd.	Taiwan	157	0	54
		5	Ind Tech Res Inst	Taiwan	106	3	15
2	PRC	1	Chinese Academy of Science[a]	PRC	1,155	14	312
		2	Univ Zhejiang	PRC	464	3	129
		3	Univ Tsinghua	PRC	461	2	91
		4	Univ Shanghai Jiaotong	PRC	409	3	75
		5	Univ Fudan	PRC	317	3	81
3	Japan	1	Nat Inst for Materials Science	Japan	334	0	60
		2	Nat Inst of Adv Ind & Technol	Japan	322	0	69
		3	Matsushita Electric Ind Co. Ltd.	Japan	263	6	37
		4	Fujitsu Ltd.	Japan	247	13	48
		5	Canon Kk.	Japan	222	11	26
4	South Korea	1	Samsung Electronics Co. Ltd.	South Korea	327	1	82
		2	Korea Inst Science Technology	South Korea	253	3	57
		3	LG Electronics Inc.	South Korea	153	2	26
		4	Samsung Sdi Co. Ltd.	South Korea	144	1	12
		5	Seoul National University	South Korea	120	0	46
5	Canada	1	Xerox Co.	US	27	0	18
		2	Nantero Inc.	US	25	0	0
		3	Nat Res Council	Canada	23	1	1
		4	Hyperion Catalysis International Inc.	USA	21	0	3
		5	Nanosys Inc.	USA	18	0	0
6	Taiwan[b]	1	Ind Tech Res Inst	Taiwan	201	0	23
		2	Hon Hai Prec Ind Co. Ltd.	Taiwan	78	0	51
		3	Univ Nat Cheng Kung	Taiwan	32	0	2
		4	IBM	USA	25	3	28
		5	Univ Nat Chiao Tung	Taiwan	17	0	3
7	Germany	1	Infineon Technologies AG	Germany	55	0	0
		2	Fraunhofer Ges Forschung	Germany	44	4	4
		3	Siemens AG	Germany	36	2	10
		4	Henkel Kgaa	Germany	31	5	0
		5	Hahn Meitner Inst Berlin Gmbh	Germany	20	0	0
8	Australia	1	Univ California	US	37	3	5
		2	Univ Northwestern	US	18	1	0
		3	Hyperion Catalysis International Inc.	US	16	3	4
		4	Nanosphere Inc.	US	15	0	1
		5	Harvard College	US	14	0	1
9	Russian Federation	1	G Obrazovatel Noe Uchrezhdenie	Russian Fed.	45	0	22
		2	Zao NT MDT	Russian Fed.	11	4	1
		3	Boreskova Inst Kataliza Sibir	Russian Fed.	10	1	3
		3	Inst Fiz Tverdogo Tela Ran	Russian Fed.	10	0	6
		3	Inst Ehlektrofiziki Ural Skogo	Russian Fed.	10	6	0

Table 4 continued

No.	Patent office/ repository	Rank	Applicant institution	Country of the institution	Number of nanotechnology patent applications (1991–2008)	2000	2008
10	Mexico	1	Procter & Gamble	USA	23	0	2
		2	Elan Pharma International Ltd.	Ireland	9	0	9
		2	Hyperion Catalysis International Inc.	USA	9	0	0
		4	Kimberly Clark Co.	USA	8	0	1
		4	Rohm & Haas	USA	8	0	0
11	UK	1	Toshiba Res Europ Ltd.	UK	13	1	4
		2	Hitachi Europ Ltd.	UK	9	0	0
		3	Gen Electric	USA	8	1	0
		4	Intel Co.	USA	7	0	3
		5	Waters Investments Ltd.	USA	6	0	0
12	France	1	Centre Nat Rech Scient	France	58	0	5
		2	Commissariat Energie Atomique	France	41	1	3
		3	O'real	France	27	0	0
		4	Rhone Poulenc Chimie	France	10	0	0
		5	Arkema Sa	France	8	0	0
13	Brazil	1	Unicamp	Brazil	13	0	1
		2	Comissao Nac de En Nuclear	Brazil	8	0	1
		3	Gen Electric	US	6	0	2
		4	Du Pont	US	5	0	5
		5	Gomes Uilame Umbelino	Brazil	5	0	1
14	Ukraine	1	Kaplunenko Volodymyr Heorhiiov	Ukraine	99	0	53
		1	Kosinov Mykola Vasyliovych	Ukraine	99	0	53
		3	Shulzhenko Oleksandr Oleksandr	Ukraine	6	0	0
		4	Lytvynenko Yurii Mykhailovych	Ukraine	5	0	0
		5	Lviv Polytekhnika Nat Universi	Ukraine	4	0	1
15	New Zealand	1	Eastman Kodak Co.	US	4	0	0
		2	Snow Brand Milk Prod Co. Ltd.	Japan	3	1	0
		3	Smithkline Beecham Co.	USA	2	0	0
		3	Technologies Avancees & Membra	France	2	0	0
		3	Univ Johns Hopkins	USA	2	0	0

[a] In our data collection, Chinese Academy of Sciences had variations of its name in English and it also has several affiliated organizations. We manually checked and came up with 27 different institution names which are all essentially Chinese Academy of Sciences. The number reported in the table is the sum of all the nanotechnology patent applications published by these 27 institutions

[b] As noted previously, data from 2007 was used for Taiwan's patent office, rather than 2008

Electric Ind Co. Ltd. In PRC's patent offices, all the leading applicants are academic or academy research institutions.

Compared with 2000, there is a general increase in the number of nanotechnology patent applications published by the top institutions in 2008. Among the top five institutions, in each of the patent offices of the USA, PRC, and Australia, the institution with the largest numbers of nanotechnology patent applications from 1991 to 2008 also ranked first in 2000.

Top technology fields

We used the International Patent Classification (IPC) class instead of the European Patent Classification (EPC) class to indicate technology fields in Table 5

Table 5 Top five technology fields in the 15 patent offices based on the number of nanotechnology patent applications from 1991 to 2008

No	Patent office/ repository	Rank	IPC class	Class name	Number of nanotechnology patent applications (1991–2008)	2000	2008
1	USA	1	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	4,203	76	743
		2	A61K	Preparations for medical, dental, or toilet purposes	1,974	51	367
		3	G01N	Investigating or analyzing materials by determining their chemical or physical properties	1,754	36	230
		4	C01B	Non-metallic elements; compounds thereof	1,453	23	187
		5	B32B	Layered products, i.e., products built-up of strata of flat or non-flat, e.g., cellular or honeycomb	1,400	15	444
2	PRC	1	A61K	Preparations for medical, dental, or toilet purposes	1,549	9	370
		2	C01B	Non-metallic elements; compounds thereof	1,501	14	392
		3	B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	1,311	11	388
		4	C08L	Compositions of macromolecular compounds	1,247	7	349
		5	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	1,095	4	350
3	Japan	1	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	2,324	81	367
		2	C01B	Non-metallic elements; compounds thereof	1,994	55	292
		3	B82B	Nano-structures manufacture or treatment thereof	1,599	35	229
		4	G01N	Investigating or analyzing materials by determining their chemical or physical properties	1,123	47	89
		5	H01J	Electric discharge tubes or discharge lamps	1,031	58	82
4	South Korea	1	B82B	Nano-structures manufacture or treatment thereof	1,280	5	417
		2	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	1,094	29	238
		3	C01B	Non-metallic elements; compounds thereof	409	5	103
		4	C08K	Use of inorganic or non-macromolecular organic substances as compounding ingredients	374	0	88
		5	H01J	Electric discharge tubes or discharge lamps	361	7	30
5	Canada	1	A61K	Preparations for medical, dental, or toilet purposes	328	8	47
		2	G01N	Investigating or analyzing materials by determining their chemical or physical properties	169	7	9
		3	B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	148	10	8
		4	C01B	Non-metallic elements; compounds thereof	144	2	23
		5	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	123	4	22
6	Taiwan[a]	1	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	367	11	47
		2	C01B	Non-metallic elements; compounds thereof	114	1	14
		3	H01J	Electric discharge tubes or discharge lamps	112	1	9
		4	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	78	2	13
		5	G01N	Investigating or analyzing materials by determining their chemical or physical properties	71	0	15

Table 5 continued

No	Patent office/ repository	Rank	IPC class	Class name	Number of nanotechnology patent applications (1991–2008)	2000	2008
7	Australia	1	A61K	Preparations for medical, dental, or toilet purposes	295	22	19
		2	C01B	Non-metallic elements; compounds thereof	212	12	7
		3	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	209	9	11
		4	B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	177	10	12
		5	G01N	Investigating or analyzing materials by determining their chemical or physical properties	163	15	4
8	Germany	1	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	165	7	17
		2	B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	135	13	10
		3	B82B	Nano-structures manufacture or treatment thereof	121	3	16
		4	G01N	Investigating or analyzing materials by determining their chemical or physical properties	111	3	13
		5	A61K	Preparations for medical, dental, or toilet purposes	103	6	8
9	Russian Federation	1	B82B	Nano-structures manufacture or treatment thereof	118	2	55
		2	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	88	4	13
		3	C01B	Non-metallic elements; compounds thereof	75	2	16
		4	B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	69	6	15
		5	A61K	Preparations for medical, dental, or toilet purposes	58	1	12
10	UK	1	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	83	2	16
		2	G01N	Investigating or analyzing materials by determining their chemical or physical properties	58	2	15
		3	B01D	Separation	30	2	2
		4	A61K	Preparations for medical, dental, or toilet purposes	29	0	7
		5	C01B	Non-metallic elements; compounds thereof	28	0	2
11	Mexico	1	A61K	Preparations for medical, dental, or toilet purposes	109	0	26
		2	B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	60	0	0
		3	C08K	Use of inorganic or non-macromolecular organic substances as compounding ingredients	58	0	8
		4	C08L	Compositions of macromolecular compounds	52	0	3
		5	C09D	Coating compositions, e.g. paints, varnishes, lacquers; filling-pastes; chemical paint or ink removers; inks; correcting fluids; wood stains; pastes or solids for coloring or printing; use of materials therefore	45	0	8
12	France	1	A61K	Preparations for medical, dental, or toilet purposes	69	0	2
		2	H01L	Semiconductor devices; electric solid state devices not otherwise provided for	61	0	6
		3	B82B	Nano-structures manufacture or treatment thereof	55	0	7
		4	C01B	Non-metallic elements; compounds thereof	47	0	7
		5	A61Q	Use of cosmetics or similar toilet preparations	45	0	2

Table 5 continued

No	Patent office/ repository	Rank	IPC class	Class name	Number of nanotechnology patent applications (1991–2008)	2000	2008
13	Brazil	1	A61K	Preparations for medical, dental, or toilet purposes	65	0	21
		2	C08K	Use of inorganic or non-macromolecular organic substances as compounding ingredients	30	0	7
		3	C08L	Compositions of macromolecular compounds	28	0	6
		4	B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	28	0	8
		5	B82B	Nano-structures manufacture or treatment thereof	24	0	12
14	Ukraine	1	B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	52	0	25
		2	C01B	Non-metallic elements; compounds thereof	24	0	3
		3	B22F	Working metallic powder; manufacture of articles from metallic powder; making metallic powder	21	0	4
		4	C12N	Micro-organisms or enzymes; compositions thereof	19	0	16
		5	C02F	Treatment of water, waste water, sewage, or sludge	18	0	4
15	New Zealand	1	A61K	Preparations for medical, dental, or toilet purposes	62	4	8
		2	A61P	Therapeutic activity of chemical compounds or medicinal preparations	28	1	3
		3	B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	20	2	4
		4	B01D	Separation	18	1	3
		5	C07K	Peptides	17	0	3

[a] As noted previously, data from 2007 was used for Taiwan's patent office, rather than 2008

because the EPC class information is incomplete in some patent offices (repositories). Among the top five technology fields in the 15 patent offices, there were 19 unique IPC classes, 10 of which ranked among the top five in more than one patent office:

- "Semiconductor devices; electric solid state devices not otherwise provided for" (H01L) ranked among the top five in 11 patent offices (except in those of Mexico, Brazil, the Ukraine, and New Zealand)
- "Preparations for medical, dental, or toilet purposes" (A61K) ranked among the top five in 11 patent offices (except in those of Japan, South Korea, Taiwan, and the Ukraine)
- "Non-metallic elements; compounds thereof" (C01B) ranked among the top five in 11 patent offices (except in those of Germany, Mexico, Brazil, and New Zealand)
- "Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus" (B01J) also ranked among the top five in nine patent offices
- "Investigating or analyzing materials by determining their chemical or physical properties" (G01N) ranked among the top five in seven patent offices
- "Nano-structures manufacture or treatment thereof" (B82B) ranked among the top five in six patent offices.

In the USPTO, "Semiconductor devices; electric solid state devices not otherwise provided for" (H01L) ranked first, followed by "Preparations for medical, dental, or toilet purposes" (A61K). Such rankings are consistent with the results reported in our previous study for granted patents. In addition, "Investigating or analyzing materials by determining their chemical or physical properties" (G01N) and "Layered products, i.e., products built-up of strata of flat or non-flat, e.g., cellular or honeycomb" (B32B), which ranked third and fifth, respectively, in this study, ranked fifth and fourth, respectively, in the previous study (Li et al. 2007). However, "Non-metallic elements; compounds thereof" (C01B), which was also among the top five, did not appear among the top 10 technology fields as reported by Li et al. (2007).

In Japan's patent office, "Semiconductor devices; electric solid state devices not otherwise provided for" (H01L) ranked first, followed by "Non-metallic elements; compounds thereof" (C01B), "Nano-structures manufacture or treatment thereof" (B82B), "Investigating or analyzing materials by determining their chemical or physical properties" (G01N), and "Electric discharge tubes or discharge lamps" (H01J). All these technology fields ranked among the top 10 in the previous study (Li et al. 2007). Except "Nano-structures manufacture or treatment thereof" (B82B), which ranked eighth in Li et al. (2007), they all ranked among the top five as well.

Compared to 2000, there were many more nanotechnology patent applications in the top five technology fields in 2008 for different patent offices, including the patent offices of the USA, PRC, Japan, South Korea, Canada, Germany, Russian Federation, the UK, Mexico, France, Brazil, the Ukraine, and New Zealand. Since the patent offices of Mexico, Brazil, and Ukraine did not have nanotechnology patent applications in 2000, there were no applications from their top five technology fields in 2000. In addition, none of the eight applications in France's patent office in 2000 belonged to its top five technology fields. In 2008, almost all the top five technology fields in each of the 15 patent offices had nanotechnology patent applications.

For the patent offices of the USA, Japan, Taiwan, Australia, and New Zealand, the technology field that ranked the first in each of them based on data from 1991 to 2008 also had the largest number of nanotechnology patent applications in 2000. In 2008, there were 13 patent offices (excepting the patent offices of PRC and France) for which the technology field which ranked first based on data from 1991 to 2008, also had the largest number of nanotechnology patent applications in 2008 (Taiwan in 2007).

Topic analysis

Content maps were used to visualize the major technology topics in different patent offices (repositories). Since the patent offices of the USA and PRC had many more nanotechnology patent applications than other countries, we created content maps for both of them. In order to get a better understanding of the topic evolution for all the 15 patent offices, we also created content maps using the data from all the 15 patent offices for years 2000 and 2008.

We used the multi-level self-organization map algorithm (Chen et al. 1996; Ong et al. 2005) developed by the Artificial Intelligence Lab at the University of Arizona. A content map has two components: a folder tree, and a hierarchical map. Each node in the folder tree, corresponding to a region in the hierarchical map, is a topic (keyword) identified from the document. Conceptually closer technology topics are positioned closer geographically. The numbers of documents assigned to the different levels of topics are presented after the topic labels. The size of each topic region also generally corresponds to the number of documents assigned to the topic. For each topic region, 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 a growth rate similar 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, respectively. If the topic is brand new, a red color is assigned to the region.

Figures 5, 6, and 7 show the content maps for the patent office of the USA in 2008 for USPTO, PRC, and for all the 15 patent offices, respectively. The data in 2008 for USPTO and all the 15 countries are compared to data in 2000. For the patent office of the PRC, the 2008 data cannot be statistically well compared to data in 2000, because the number of nanotechnology patent applications in 2000 is too limited to generate a content map at that date.

Compared with 2000, the nanotechnology patent applications published in the USPTO in 2008 (Fig. 5) have a baseline growth rate of 16.14 times, indicating a significant increase in nanotechnology research. Topics that appear in both years are: "Aqueous solutions," "Dielectric layers," and "Metal oxides," each of which had many more applications in 2008 than in 2000.

Topics which appeared in 2000 only included:

- Nanomaterial-related topics, such as "Carbon atoms," "Carbon nanotubes," and "Memory cells"
- Properties of nanomaterials, such as "Average molecular weight," "Low dielectric," "Molecular weights," and "Surface roughness"

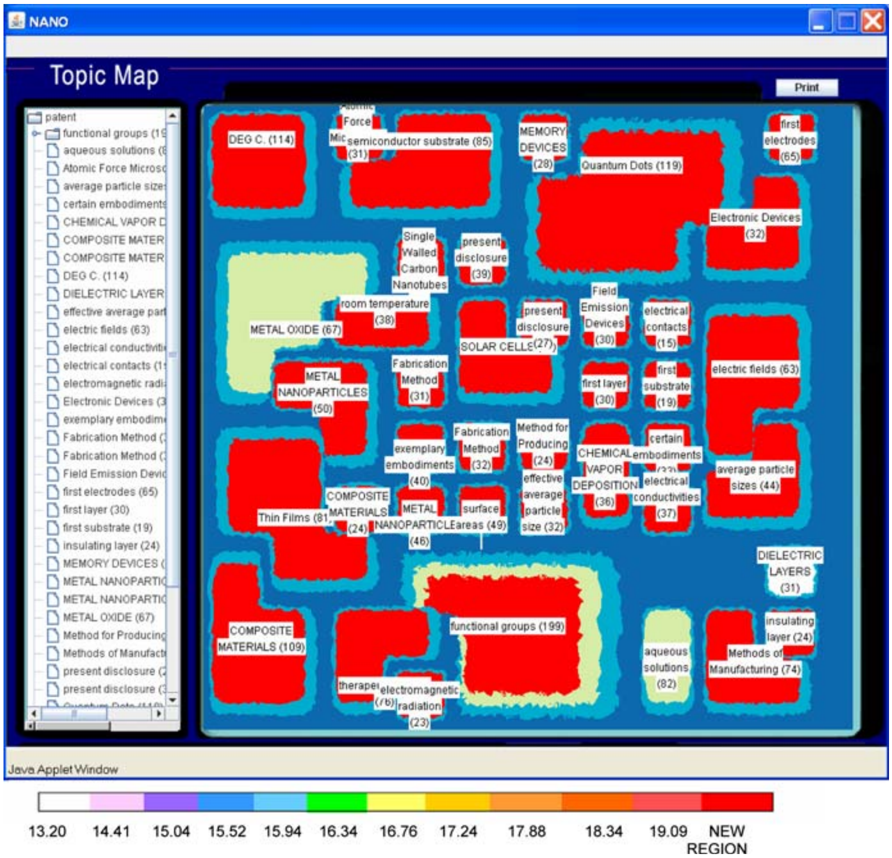


Fig. 5 The content map for patent applications at the USPTO in 2008 (the *color* means the rate of increase as compared to 2000; the "new region" in *red* is 92%)

- Nano-device related topics, such as "Alkali metals," "Laser beams," "Light source," "Magnetic recording medium," "Silicon substrates," "Substrate surfaces"
- Measurement- and method-related topics, such as "Nanometers at reaction conditions," "Surface roughness," and "Ultraviolet radiation."

The newly emerging topics of 2008 included:

- Nanomaterial-related topics, such as "Composite materials," "Metal nanoparticles," "Quantum dots," "Single walled carbon nanotubes," "Solar cells," and "Thin films"
- Properties of nanomaterials, such as "Average particle sizes," "Effective average particle size," and "Electrical conductivities"
- Nano-device related topics, such as "Electric fields," "Electronic devices," "Field emission devices," "Insulating layer," "Memory devices," "Semiconductor substrate," "Therapeutic agents"
- Measurement- and method-related topics, such as "Atomic force microscope," "Chemical vapor deposition," "Electromagnetic radiation," and "Fabrication method."

As shown in Fig. 6, the largest topic in the patent office of the PRC in 2008 was "human bodies" with 295 nanotechnology patent applications. Topics related to nanomaterials included "Carbon nanotube," "Composite materials," "Nanometer materials," "Quantum dots," and "Thin films." Topics related to properties of nanomaterials were "Good stability," "Grain diameter," "High activity," "High sensitivity," "Molar ratio," "pH values," "Service life," and "Weight percentages." Topics related to nano-device included "Deionized water," "Organic solvents," and "Stainless steels." Topics related to measurements and methods included "Aqueous solutions," "Convenient operation," "Production method," and "Water solution."

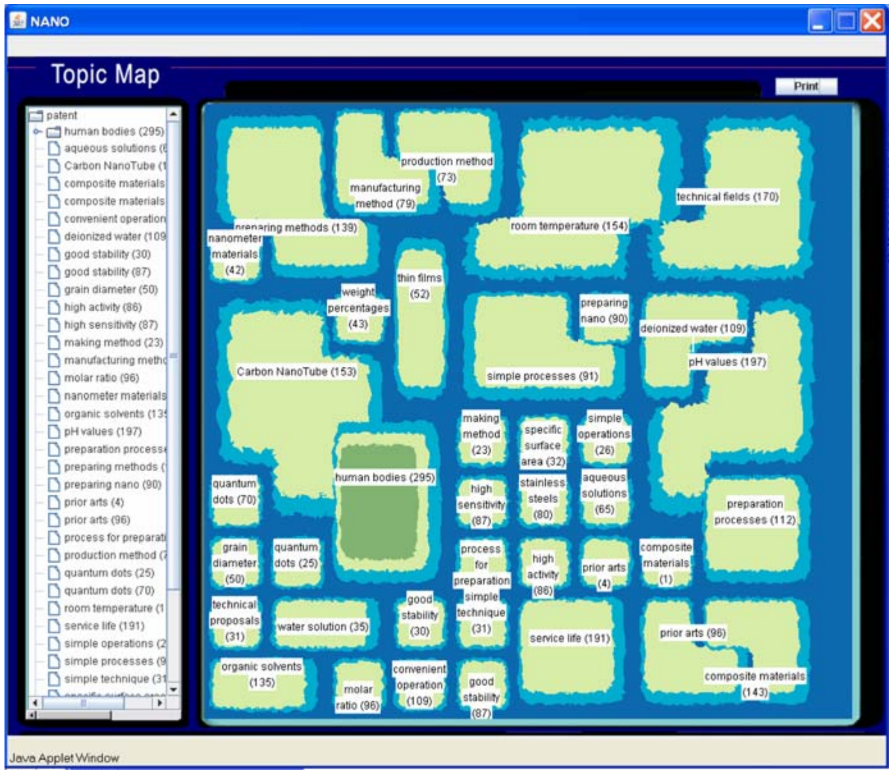


Fig. 6 The content map for the patent office of the PRC in 2008

Compared with 2000 the nanotechnology patent applications published in all, the 15 patent offices in 2008 (Fig. 7) had a baseline growth rate of 12.57, indicating a significant increase in nanotechnology research. Six main topics that appeared in both years included:

- "Average particle size"
- "Aqueous solutions"
- "Metal oxides"
- "Manufacturing method"
- "Thin films"
- "Functional groups"

Each of these topics had significantly more applications in 2008 than in 2000.

Older main topics that appeared in 2000 only included:

- Nanomaterial-related topics, such as "Carbon nanotube," "Composite materials," "Organic polymer," "Quantum dot," and "Such films"
- Properties of nanomaterials, such as "Average pore diameter," "Average size," "High densities," "Molecular weights," "Surface roughness," "Weight ratio," etc.
- Nano-device related topics, such as "Electric fields," "Electron beams," "Laser beams," "Light source," "Magnetic cores," "Semiconductor substrates," and "Transition metals"
- Measurement- and method-related topics, such as "Atomic force microscope," "Electromagnetic radiation," and "Ultraviolet radiation"

The newly emerging topics for 2008 included:

- Nanomaterial-related topics, such as "Composite materials," "Metal nanoparticles," and "Quantum dots"
- Properties of nanomaterials, such as "pH values," "High purities," and "Particle diameters"
- Nano-device related topics, such as "Organic solvents," "Semiconductor Devices," "Deionized water," and "Gate electrodes"

There were no new topics related to certain measurements or methods.

Patent family analysis

The patent office of each country or region has the jurisdiction to grant a patent for its own geographic area only. In order to achieve broader coverage of the exclusive rights for an invention, some patent applications are filed in multiple countries'/regions' patent offices, and, thus, become a patent family. All the patent applications (or granted patents) in a given patent family are equivalents and considered to be one invention.

Patent family analysis within each patent office

Table 6 lists the numbers of nanotechnology patent applications published in single patent office, two or more patent offices, and three or more patent offices. For example, 2,939 patent applications that were published in the US patent office had been also published in at least one other patent office. Among those patent applications, 741 had been published in three or more countries'/regions' patent offices. The patent offices of Japan, the PRC, and South Korea also had relatively larger numbers of nanotechnology patent applications published in multiple patent offices.

For each patent office, we also identified other patent offices with which it shared the greatest numbers of nanotechnology patent applications for the interval between 1991 and 2008. For example,

- The top five patent offices sharing nanotechnology patent applications with the USPTO were Japan (1,258), PRC (725); South Korea (636), Taiwan (353), and Canada (350). Our analysis shows that all other patent offices (except for Brazil's patent offices) shared the largest numbers of nanotechnology patent applications with the USPTO.
- The top five patent offices sharing nanotechnology patent applications with the PRC repository were those of the USA (725), South Korea (624), Japan (416), Taiwan (68), and Canada (40).
- The top five patent offices sharing nanotechnology patent applications with the JPO were those of the USA (1258), South Korea (450), PRC (416), Taiwan (107), and Canada (106).

Patent family analysis across patent offices

The network in Fig. 8 shows patent families across patent offices. In the network, nodes represent different countries'/regions' patent offices. The bigger the node, the higher the number of nanotechnology patent applications it shares with other countries'/regions' patent offices. The number of nanotechnology patent applications each patent office shared with others is

Table 6 Numbers of nanotechnology patent applications published in single patent office, two or more patent offices, and three or more patent offices (1991–2008)

No.	Patent office (repository)	No. of patent applications published in total	No. of patent applications published in a single patent office	No. of patent applications published in ≥2 patent offices	No. of patent applications published in ≥3 patent offices
1	USA	19,665	16,726	2,939	741
2	PRC	18,438	17,079	1,359	490
3	Japan	10,763	9,084	1,679	614
4	South Korea	5,963	4,731	1,232	491
5	Canada	1,539	988	551	160
6	Taiwan	1,363	900	463	123
7	Australia	1,312	926	386	91
8	Germany	1,296	1,229	67	21
9	Russian Federation	859	785	74	31
10	Mexico	471	228	243	96
11	UK	412	291	121	32
12	France	390	339	51	17
13	Brazil	315	167	148	70
14	Ukraine	243	231	12	6
15	New Zealand	140	68	72	38

Fig. 7 The content map for all 15 patent offices in 2008 (the *color* means the rate of increase as compared to 2000; the "new region" in *red* is 68%)

presented in parentheses after the node label. The link between two patent offices means that they have published nanotechnology patent applications in the same patent families. The thicker the link, the greater the number of nanotechnology patent applications the two patent offices shared. The number beside the link indicates how many nanotechnology patent applications the two patent offices shared. The network was drawn using open source software, NetDraw (available at: http://www.analytictech.com/Netdraw/netdraw.htm/).

Each of the top 15 patent offices shared nanotechnology patent applications with other patent offices. The USPTO shared the largest number of nanotechnology patent applications with others (2,939), followed by the patent offices of Japan, PRC, and South Korea (1,679; 1,359; and 1,232 nanotechnology patent applications, respectively). The thickest link in the network shows that the patent offices of the US and Japan shared the largest number of nanotechnology patent applications (i.e., 1,258 applications).

We have identified 12 patent families that had equivalent nanotechnology patent applications published in at least five patent offices. The titles of the equivalent patents may or may not be the same.

Conclusions

The nanotechnology patent applications published in different countries'/regions' patent offices have been evaluated by using the *esp@cenet* "worldwide" database. Key findings from the longitudinal analysis of nanotechnology patent applications between 1991 and 2008 are:

- The worldwide growth rate of the number of nanotechnology patent applications between 2000 and 2008 is about 34.5% (Fig. 1). This rate is larger than the corresponding rate of increase for International Citation Index articles of about 25%. The baseline growth rates of the number of patent applications for continuing

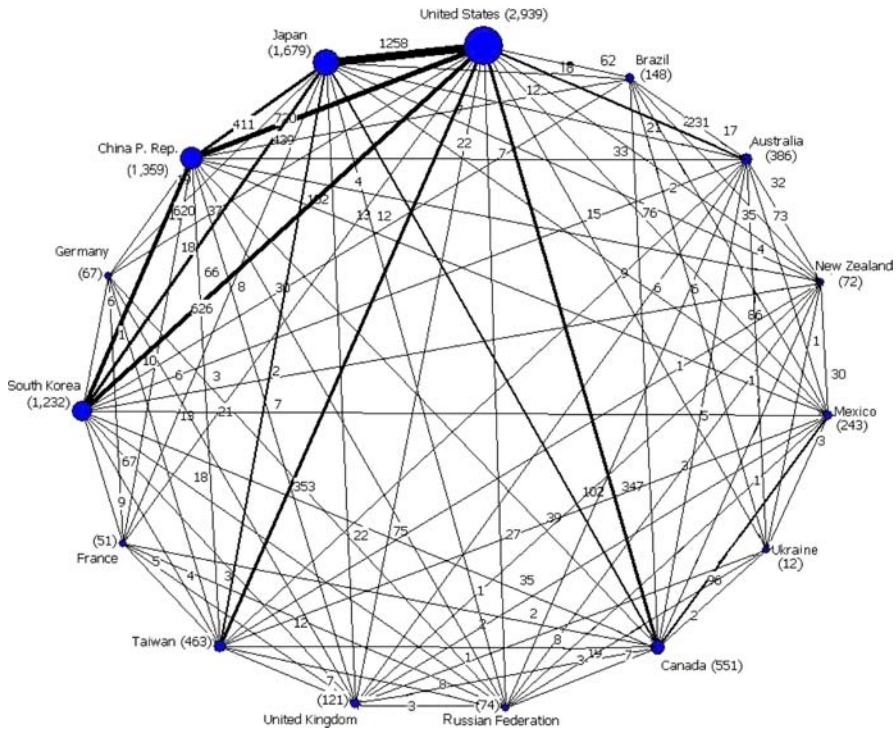


Fig. 8 Patent families across leading 15 patent offices for nanotechnology applications from 1991 to 2008

topics are 16.14 and 12.57 times in the interval from 1991 to 2008 for the USPTO and the top 15 nanotechnology patent repositories, respectively. The new nanotechnology topics in 2008 as compared with 2000 represent 92% in the USA (Fig. 5) and 68% for top 15 repositories (Fig. 7). The baseline growth rate is significant in the PRC patent office, but the data available in 2000 are too limited to generate a content map in that year for comparison with 2008. The largest number of nanotechnology patent applications, as well as of the patent application families, are at the patent offices of the USA, PRC, Japan, and South Korea.

- A higher number of nanotechnology patent applications are published by applicants from their own countries/regions, indicating significant "home advantage" effects. The USA, Japan, Germany, South Korea, and France were the largest contributors in patent offices other than its repository. The top 15 patent offices except for Brazil's patent office shared the largest numbers of nanotechnology patent applications with the USPTO. Japan is the USPTO's largest partner co-sharing 1,258 nanotechnology patent applications.
- Applicant institutions with large international activity are illustrated by IBM (from the USA), the University of California (from the USA), Samsung Electronics Co. Ltd. (from South Korea), Hon Hai Prec Ind Co. Ltd. (from Taiwan), and Industrial Technology Research Institute (Ind Tech Res Inst; from Taiwan), Hyperion Catalysis International Inc. (from the USA), and General Electric (Gen Electric, from the USA).
- The ranking of the most productive institutions and the categories of the lead technology fields in patent repositories have had relatively small changes over time, and few institutions or categories of technology fields were able to break into the top ranks. However, specific topics within various technology field categories changed rapidly after 2000. Topics that increased in 2008 in most of the 15 patent offices included: "Composite materials," "Deionized water," "Gate electrodes," "High purities," "Metal nanoparticles," "Organic solvents," "Particle diameters," "PH values," "Quantum dots," and "Semiconductor Devices."
- Several top technology fields (represented by IPC class) were shared by multiple repositories.

"Semiconductor devices; electric solid state devices not otherwise provided for" (H01L) was among the top five technology fields in 11 out of the 15 patent offices. The following fields ranked among the top five in multiple repositories: "Preparations for medical, dental, or toilet purposes" (A61K), "Non-metallic elements; compounds thereof" (C01B), "Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus" (B01J), "Investigating or analyzing materials by determining their chemical or physical properties" (G01N), and "Nano-structures manufacture or treatment thereof" (B82B).

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