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PERSPECTIVES

Nano Mapper: an Internet knowledge mapping system for nanotechnology development

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Abstract Nanotechnology research has experienced rapid growth in recent years. Advances in information technology enable efficient investigation of publications, their contents, and relationships for large sets of nanotechnology-related documents in order to assess the status of the field. This paper presents the development of a new knowledge mapping system, called Nano Mapper (http://nanomapper.eller.arizona.edu), which integrates the analysis of nanotechnology patents and research grants into a Web-based platform. The Nano Mapper system currently contains nanotechnology-related patents for 1976–2006 from the United States Patent and Trademark Office (USPTO), European Patent Office (EPO), and Japan Patent Office (JPO), as well as grant documents from the U.S. National Science Foundation (NSF) for the same time period. The system provides complex search functionalities, and makes available a set of analysis and visualization tools (statistics, trend graphs, citation networks, and content maps) that can be applied to different levels of analytical units (countries, institutions, technical fields) and for different time intervals. The paper shows important nanotechnology patenting activities at USPTO for 2005–2006 identified through the Nano Mapper system.

Keywords Nanotechnology · Research and development (R&D) · Patent analysis · Grant analysis · Bibliographic analysis · Information visualization · Self-organizing maps · Citation network · Data analysis tool

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Introduction

Nanotechnology has revolutionized numerous application domains and is widely recognized as a critical indicator of a country's technological competence. More than 60 countries have adopted national projects or programs, such as the United States' *National Nanotechnology Initiative* (NNI, http://www.nano.gov) (Roco et al. 2000), to support nanotechnology research. The funding made available from various public and private resources and the growing interest in this domain have contributed to its rapid development and public recognition.

Different analysis methods have been proposed to assess nanotechnology's development status. Patents have been used to represent commercialized research results in nanotechnology (Meyer 2001; Huang et al. 2003b, 2004), grant documents have been used to study the effect of public funding on nanotechnology (Huang et al. 2005; Roco 2005), and academic literature has been used to represent the research efforts in academia (Schummer 2004; Kostoff et al. 2006). During the past 30 years, a large number of scientific documents on nanotechnology development have been generated and stored in various databases around the world. However, previous studies have focused primarily on applying certain analytical techniques on specific data sets (in specific time periods and regions) to answer specific research questions. Few of them have had the intention of making the analytical tools and data sets available to the public.

The proposed Web-based knowledge mapping system has the potential to support the assessment of nanotechnology development by making the massive volume of nanotechnology-related documents available and by providing a set of flexible and easy-to-use analysis tools. However, a number of technical challenges need to be addressed for a system to function effectively:

- *Distributed collection of data/documents*: Patents are published by the patent offices of different countries. Academic literature is published in various journals and stored in different databases. Searching for and collecting nanotechnology-related documents from multiple databases (each with its own interface) from around the world requires several different procedures and processes.
- *Unstructured data/document formats*: Although digitized documents have been widely used in the storage of patents, grants, and other types of documents, such documents usually contain different data fields. To make the unstructured data ready for analysis, significant efforts are needed for data parsing and preprocessing.
- *Implementation of the analysis tools*: The analysis tools need to be tailored to different documents' characteristics and data fields. Algorithms for analyzing large-volume data sets in real time may need to be re-designed.

Due to these challenges, there are few knowledge mapping systems for scientific document analysis in the public nanotechnology domain. We therefore proposed a framework to use in building such knowledge mapping systems in order to analyze nanotechnology status. In the paper, we discussed the prototype system we created, Nano Mapper, which provides integrated Web access to a variety of visualization and analytical tools for nanotechnology patents from the United States Patent and Trademark Office (USPTO), European Patent Office (EPO), and Japan Patent Office (JPO) and grants from the U.S. National Science Foundation (NSF). In the current system, we do not include academic literature for copyright reasons.

In Section "Research background" of this paper, we briefly review the previous patent and grant analysis studies, and discuss existing nanotechnology Web portals/knowledge portals. In Section "Nano Mapper system design," we present our methodology and Nano Mapper's architecture and major functionalities. In Section "Nanotechnology Development in USPTO (2005–2006)," we analyze the nanotechnology patents published in the USPTO in 2005–2006 using Nano Mapper. Section "Conclusions" concludes the paper by summarizing our findings and discussing future work.

Research background

Patent analysis

Patents contain rich information about technology innovations. A large number of patents published in patent offices around the world are publicly available. As an important indicator of technological advancement, patents have been widely used to assess the research and development status of different domains (Narin 1994; Karki 1997; Oppenheim

2000), including nanotechnology (Huang et al. 2003b), gastroenterology (Lewison 1998), and high-technology fields (Huang et al. 2003a). In the nanotechnology domain, Meyer studied the interrelationships between academia and industry using patents from the USPTO and scientific literature from the Thomson Science Citation Index (Meyer 2001). Hullmann et al. used bibliometric measures on both patents and literature to assess nanotechnology's status in the 1980s and 1990s (Hullmann and Meyer 2003). Huang et al. extended previous studies and developed a patent analysis framework that included bibliometric analysis, content analysis, and citation analysis to assess nanotechnology development at the country, institution, and technology field levels (Huang et al. 2003b, 2004).

Patents are managed by different patent offices throughout the world. Although many studies have used data from a single office, such a method may lead to biased analysis results. Previous research found that domestic applicants tend to file more patents with their home country patent office than foreign applicants do ("home advantage" effect) (European Commission 1997). This "home advantage" effect affects the composition of patents in patent databases (Ganguli 1998; Criscuolo 2006). In addition, patent offices worldwide have different examination procedures and policies, which may also affect patent publication and patent contents. To provide a more comprehensive understanding of global nanotechnology development, the patents from multiple patent offices have been analyzed (Li et al. 2007b; Chen et al. 2008).

Grant analysis

In recent years, a significant amount of public funding has been devoted to nanotechnology. In the United States, >5% of the National Science Foundation (NSF) budget was dedicated to supporting nanotechnology research in 2005 (Roco 2005). In Europe, funding from the European Commission and individual countries comprises the major portion of nanotechnology funding (Hullmann 2006).

Previous research has studied the impact of public funding on research and innovation in different domains by analyzing grant documents. Many of these studies used scientific publications as indicators of research output (Adams and Griliches 1998; Arora and Gambardella 1998; Narin 1998; Payne and Siow 2003) and found that the impact of public funding is dependent on the particular technology field. In the nanotechnology domain, Huang et al. (2005) studied the relationship between NSF funding and patent publications. They found that the patents published by NSF-funded researchers had a significantly higher impact on the nanotechnology domain as compared to other reference groups. They also found that the topics in grants change faster than those in patents.

Web portals for nanotechnology

In response to the rapid development of nanotechnology after 2000, several Web portals have been built to provide improved access to nanotechnology-related information (Table 1). The first type of portal focuses on providing nanotechnology-related news articles, interviews, and research reports, such as "Nanotechnology Now," "Nano Tsunami," and "Nano Science & Technology Institute." The second type of portal aims to build a hub of URLs to nanotechnology Websites, forums, books, journals, databases, etc., such as "ENS Nanotechnology Portal" and "Nano Scout." The third type of portal provides access to nanotechnology equipment, education materials and software; examples include "National Nanotechnology Infrastructure Network," and "NanoHUB." Lastly, there are Websites available that maintain the roadmap/history of nanotechnology and provide an introduction to the domain; one such example is the "Wikipedia Nanotechnology Portal." These Websites can help researchers find nanotechnology-related information, but they do not systematically collect nanotechnology-related scientific documents or provide functionality for analyzing nanotechnology development. The well-established patent and grant analysis methods in previous studies have not been widely implemented in actual online applications/Websites. Building online systems with patent and grant analysis functionalities may better assist researchers and policy makers in nanotechnology to analyze the data and make decisions.

Nano Mapper system design

In this research project, we proposed a framework for building knowledge mapping systems for patent

Table 1 Major nanotechnology knowledge portals

Web portals	URL	Focus
ENS Nanotechnology Portal	http://www.ensbio.com/nanotechnologyPortal.html	URLs for online resources
Nanotechnology Now	http://www.nanotech-now.com	News and research reports
National Nanotechnology Infrastructure Network (NNIN)	http://www.nnin.org	Equipment
NanoHUB	http://www.nanohub.org	Education and software for modeling and simulation
Nanotechnology Informal Science and Education Network (NISE)	http://www.nisenet.org	Public museum and other informal nanoscience and engineering education
Nanotechnology Center of Learning and Teaching (NCLT)	http://www.nclt.us	K-16 nanoscale science and engineering education
Nano Science & Technology Institute	http://www.nsti.org	News and academic conference information
Nano Scout	http://www.nanoscout.de	URLs to online resources
Nano Tsunami	http://www.nano-tsunami.com	News
Wikipedia Nanotechnology Portal	http://en.wikipedia.org/wiki/Portal:nanotechnology	Nanotechnology roadmaps and introductions

analysis and grant analysis for the nanotechnology domain. The framework contains three steps (see Fig. 1): data acquisition, parsing, and system building. We integrated multiple patent and grant data sets and selected data analysis and information visualization tools into one system. Our prototype system, Nano Mapper (http://nanomapper.eller.arizona.edu), is based on this framework.

Data acquisition

We used keyword searching to collect nanotechnology-related documents (i.e., patents and grants) in various databases. Table 2 shows a list of nanotechnology keywords provided by domain experts that was used to search and retrieve documents from the online interfaces of the existing databases.

In Nano Mapper, the patents were collected from USPTO, EPO, and JPO which collectively cover three major regions in nanotechnology research (Huang et al. 2003b). USPTO provides online full-text access to patents issued since 1976, which can be searched using almost any of a patent's data fields. EPO's database, esp@cenet, provides access to European patents issued since 1978, which can be searched based on title, abstract, and some bibliographic information. The site esp@cenet also stores >80 countries' patent applications. The JPO patent database (Patent Abstracts of Japan, PAJ) contains patents issued since 1976. This system is difficult to use for searching and retrieving patents. We chose to retrieve JPO patent applications from esp@cenet and check their publication status (whether application or registered patent) through PAJ. We kept only registered patents in our study.

Grants were retrieved from the NSF grant database. NSF provides online access to grant abstracts, which can be searched using almost any of a grant's data fields.

Different databases provide different search interfaces to search patents, grants, or other documents. All four databases used to build the Nano Mapper prototype support keyword searching in document titles and abstracts ("title-abstract" search). Moreover, USPTO enables more complex search functions. Following the suggestions of domain experts, we also searched USPTO nanotechnology patents by matching the keywords on patent title, abstract, and claims ("title-claims" search) and on the entire patent document ("full-text" search) (Huang et al. 2003b). In general, "title-abstract" search provided more accurate results concerning the nanotechnology contents, while the other two search methods provided better coverage of nanotechnology-related patents. Table 2 shows the number of documents collected with each nanotechnology keyword from the four databases by different search methods.

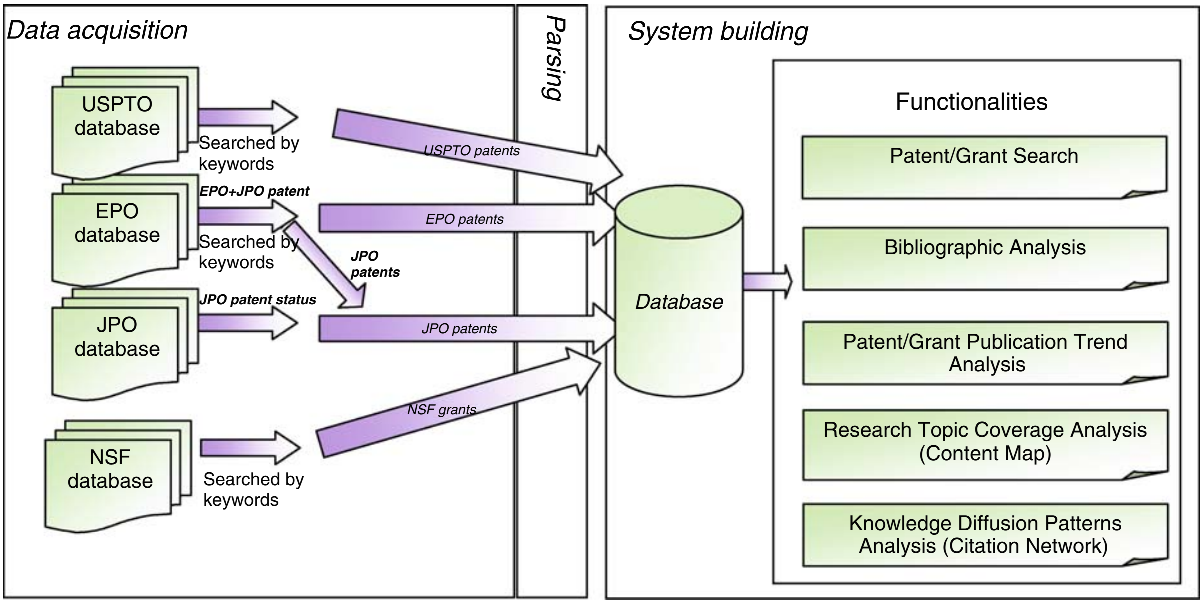


Fig. 1 Framework for building nanotechnology knowledge mapping systems

Parsing

The documents retrieved from online databases are usually free text in html format. These documents need to be parsed into structured data and stored in a relational database. In general, each data source needs a separate parser. However, since the search interfaces seldom change, the parsers can be reused to annually update data collections for the system. In the Nano Mapper system, the patent parsers extract patent identification information (patent id, patent application number, patent priority number), bibliographic information (publication date, inventor name, applicant name), classification information (International classification, United States classification, European classification), citation information, and content information (title, abstract, claims, and description) from patents. The grant parsers extract grant ID, bibliographic information (start and expiration date, grant amount, principal investigator), funding agent information (NSF organization, program, and directorate), and content information (title, abstract) from grants.

System building

After parsing the collected documents into a database, a knowledge mapping system can be built based on the architecture shown in Fig. 2. It is a three-layer structure which contains a presentation layer, a logic control layer, and a database layer.

The presentation layer implements the user interface and provides Web access to five types of functions: search function, basic statistics, trend analysis, citation network analysis, and content map analysis. The search and statistics functions are implemented with JSP (Java Server Pages) dynamic pages. The visualizations are implemented using Java Applet. To visualize patent and grant publication trends in charts, we customized an open source java library—Chart 2D (http://chart2d.sourceforge.net). To visualize the citation networks, we customized an open source graph drawing software—Graphviz, provided by AT&T Labs (http://www.research.att.com/sw/tools/graphviz) (Gansner and North 2000). In order to visualize the content maps of nanotechnology-related patents and grants, we used the content map package developed by the Artificial Intelligence Lab, University of Arizona (http://ai.arizona.edu).

At the logic control layer, SQL queries are designed to perform search and analytical functions. To handle large data sets and provide online analysis of statistics, trends, and citation networks, some pre-computing is conducted and the publication statistics and citation statistics are summarized to year level. Searching these intermediate tables saves user query time. For content analysis, we identified major

Table 2 Nanotechnology keywords and the number of patents collected from USPTO, EPO, JPO and grants collected from NSF

Keywords	USPTO (1976–2006)			EPO (1978–2006)	JPO (1976–2006)	NSF (1991–2006)
	Title-abstract search	Title-claims search	Full-text search	Title-abstract search	Title-abstract search	Title-abstract search
Atomic force microscope	277	465	3,020	71	67	241
Atomic force microscopic	2	6	91	2	1	16
Atomic force microscopy	91	143	2,347	23	8	430
Atomic force microscope	0	0	6	0	0	40
Atomic force microscopy	0	0	5	0	0	67
Atomistic simulation	0	0	10	0	0	107
Biomotor	0	1	8	1	0	0
Molecular device	9	22	230	5	3	371
Molecular electronics	5	5	422	4	3	384
Molecular modeling	34	51	2,365	3	1	1255
Molecular motor	2	3	99	4	0	135
Molecular sensor	0	9	48	2	1	185
Molecular simulation	2	2	73	1	1	449
Nano*	6,352	15,973	90,093	3,248	847	8,121
Quantum computing	28	41	144	4	1	471
Quantum dot*	160	267	988	64	90	524
Quantum effect*	40	65	699	18	67	435
Scanning tunneling microscope	148	218	1,284	47	80	190
Scanning tunneling microscopic	0	1	25	0	1	8
Scanning tunneling microscopy	28	52	996	8	0	326
Scanning tunneling microscope	0	0	24	0	0	11
Scanning tunneling microscopy	0	1	1	0	0	24
Self-assembl*	3	4	31	1	0	13
Self-assembly	161	268	2,692	46	7	316
Self-assembled	251	460	2,672	38	1	241
Self-assembling	131	208	1,237	57	5	187
Self-assembled	233	426	2,506	0	0	570
Self-assembling	120	189	1,127	0	0	286
Self-assembly	142	239	2,478	0	5	772
Total	8,219	19,119	115,721	3,647	1189	16,175
Unique total	7,406	17,544	97,509	3,596	1150	10,114

* Represents any combination of letters or numbers

technology topics from the nanotechnology documents and generated content maps using the self-organizing map (SOM) algorithm (Chen et al. 1996; Ong et al. 2005). This is a time-consuming process, so content maps for selected time periods only are made available.

At the database layer, we use Microsoft SQL Server 2000 to store parsed patent and grant data for Nano Mapper.

Nano Mapper system functionalities

Search functions

The Nano Mapper system provides three searching functions for patents and grants. Users may search using:

– Patent/grant identifiers.
– Keywords in title, abstract, or (patent) claims

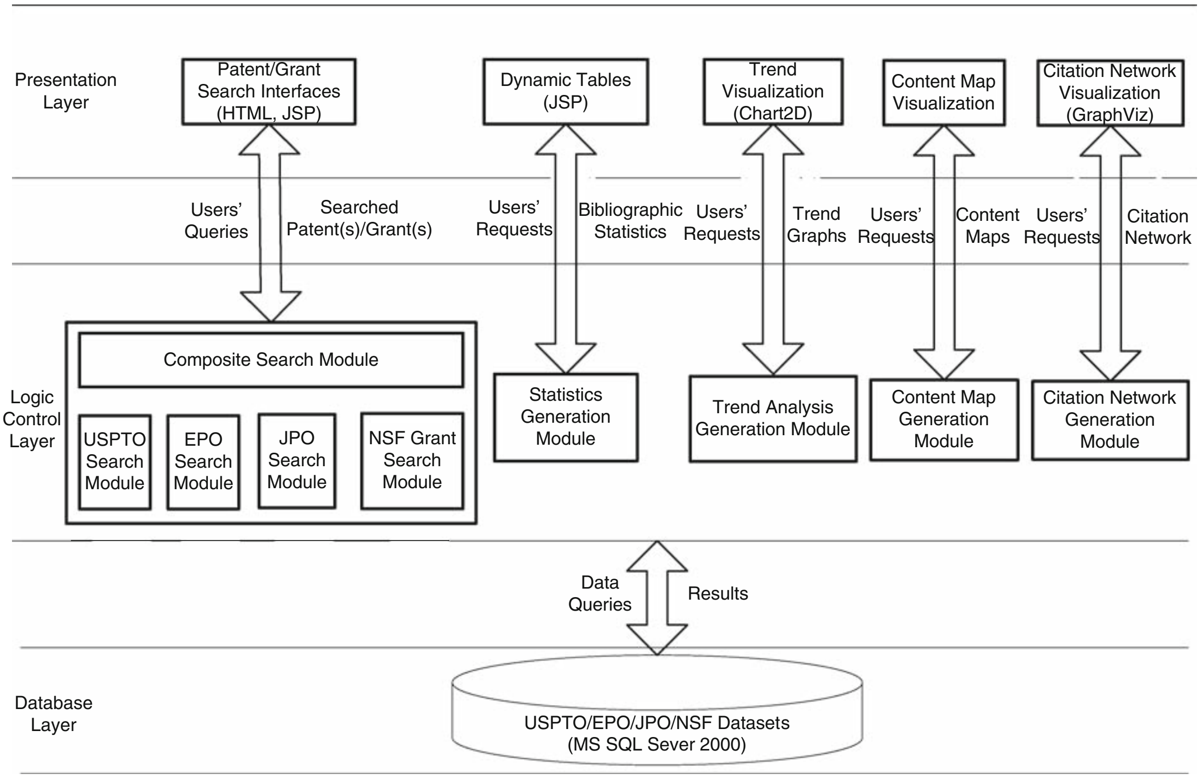


Fig. 2 System architecture of the Nano Mapper

– A combination of criteria on different patent/grant data fields (i.e., advanced search).

Nano Mapper also provides a combined search function, which searches for keywords in title/abstract on all four data sets simultaneously. The results from the four databases are shown together in one interface, which can then be browsed and compared.

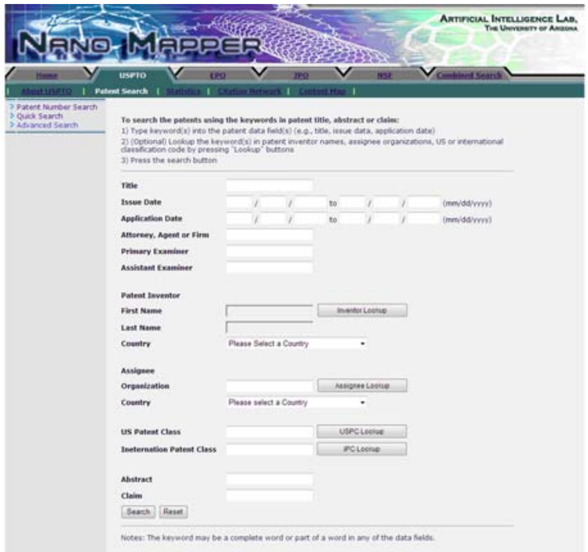
Figure 3 illustrates the advanced search function using the USPTO data set as an example. In advanced search, the interface enables users to input criteria on most data fields. On USPTO patents, the data fields include patent title, examiner, inventor, assignee, assignee country, classification code, abstract, claims, etc. For some categorical data fields, e.g., assignee country, the interface provides lookup functions to help find the appropriate search criteria. For a user query, the result set will be sorted by publication date in a reverse order. The user can browse the results using the navigation bar at the bottom. The user can also access the details of any document, including all data fields in our system and the URLs to their original Websites.

Basic statistics

The Nano Mapper can calculate and display the statistics on patent/grant publication and citation status for selected time periods at different analytical levels. Figure 4 shows the interface of statistics generation with USPTO patents. For patents, the user can set the analytical level as country, institution, inventor, or technology field. The results can be sorted by the number of patents, the number of cites, and the average number of cites each analytical unit has. For USPTO patents, the user can restrict the statistics generation in the range of the data collected using any of the three search methods. The statistics can be downloaded in CSV format for further off-line study.

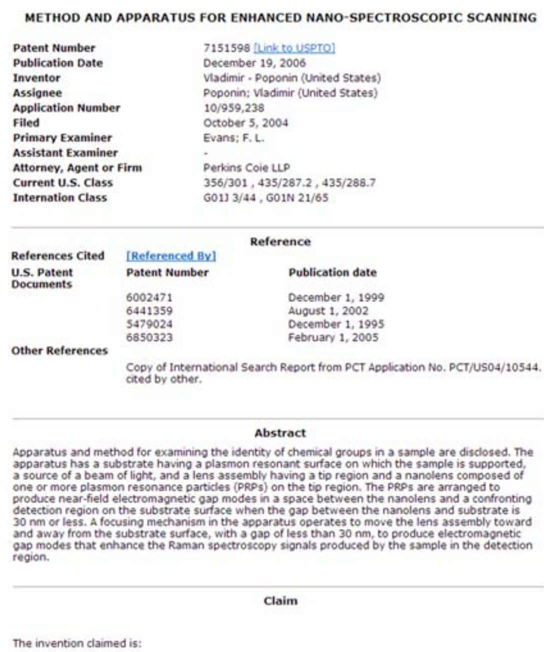
Publication trend analysis

Nano Mapper can visualize and compare the annual publication trends of patents and grants at different analytical levels. Figure 5 shows the country level analysis on USPTO patents. The analytical units



(a)

(b)



(c)

Fig. 3 Advanced search in Nano Mapper system (**a**) Search interface (**b**) Sample of result sets (**c**) Details of a patent (the contents of claims and description are omitted here)

(countries in Fig. 5) can be easily modified. To add analytical units of interest, the user can search for names in a pop-up window. The interface also provides shortcuts to add the top 10 or the top 11 to 20 most productive analytical units into the comparison. The analysis results include a line chart and a table of statistics showing the different units' number of publications in each year. The statistics can be downloaded in a CSV file format for further off-line study.

Rank	Country Name	Number of patents	Number of cites	Average number of cites
1	United States	65349	169688	2.596642
2	Japan	10974	18387	1.675505
3	Federal Republic of Germany	3351	3810	1.136974
4	France	2802	3620	1.291934
5	Canada	1427	2298	1.610371
6	United Kingdom	1283	2201	1.715510
7	China (Taiwan)	929	831	0.894510
8	Republic of Korea	883	776	0.878822
9	Netherlands	837	1045	1.248506
10	Switzerland	686	1045	1.523323
11	Australia	616	726	1.178571
12	Italy	478	419	0.876569
13	Israel	470	798	1.697872
14	Sweden	395	623	1.577215
15	Belgium	346	399	1.153179
16	Denmark	193	107	0.554404
17	Finland	171	236	1.380116
18	Singapore	141	160	1.134751
19	India	101	21	0.207920
20	Norway	96	296	3.083333

Fig. 4 Country level statistics for nanotechnology-related patents in USPTO

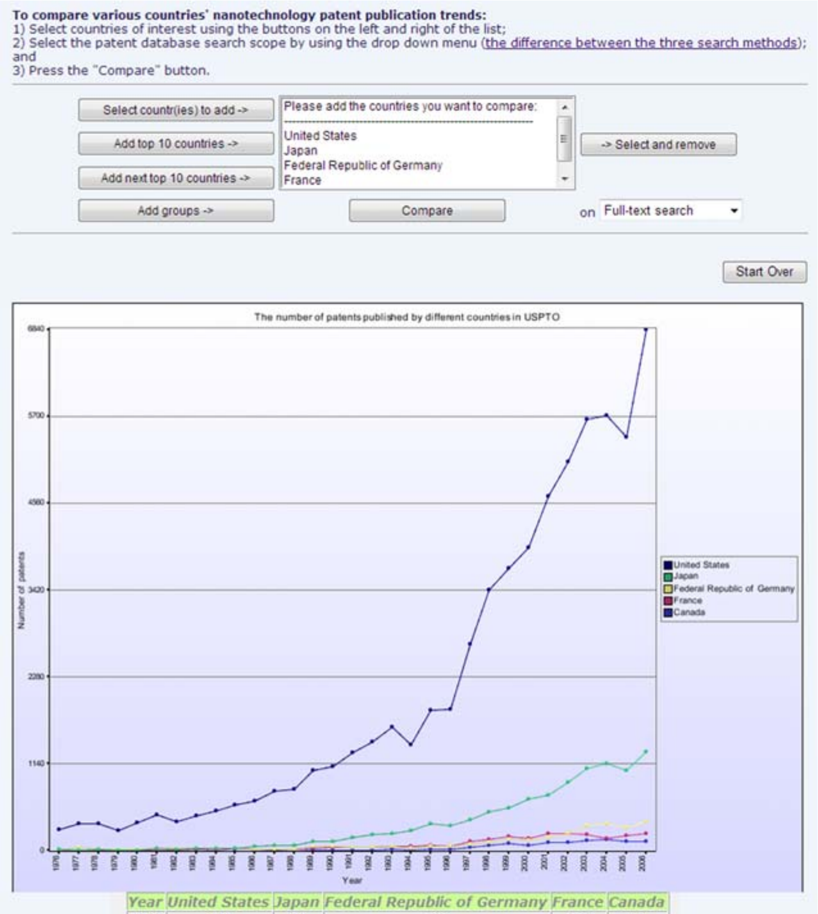
Citation network analysis

Nano Mapper enables users to visualize patent citation networks at different analytical levels for different time periods (Fig. 6), which can be used to assess knowledge diffusion patterns (Huang et al. 2003b; Kostoff et al. 2006; Li et al. 2007a). To emphasize the more important citation relationships, the top 100 relationships between analytical units with the largest number of citations are visualized. In citation networks, the direction of a link represents the direction of the citations between two nodes. For example, a link from the "United States" pointing to "Germany" means that the United States' patents cited German patents. Each link is labeled with the total number of citations.

Content map analysis

Nano Mapper uses content map technology in order to identify and visualize major nanotechnology topics for different time periods in the document titles and abstracts. The research topics are represented by noun phrase keywords extracted from patent/grant documents using a Natural Language Processing tool, the Arizona Noun Phraser. The topics are organized by the multi-level self-organizing map algorithm (Chen et al. 1996; Ong et al. 2005) and visualized by the content map interface. As Fig. 7 shows, the content map interface contains two components: a folder tree (on the left side in Fig. 7) and a hierarchical content map. The folder tree displays the topics identified from nanotechnology-related patents or grants. The hierarchical content map displays corresponding topic regions in the map. Each topic region is labeled with the topic keyword and the number of documents. The size of a topic region is proportional to the number of documents related to that topic. Conceptually, more similar topics (according to their co-occurrence patterns in documents) are positioned closer on the map. If the user clicks a topic region, the sub-topics will be expanded on the interface. If there are no sub-topics, the documents related to the selected topic will be shown.

Since generating a content map is time-consuming, we pre-generated a set of content maps for a sequence of time periods for each data set. For the content maps of two continuous time periods, we computed the growth rate of each topic area between the two maps. A baseline growth rate is computed at the entire content map level. A topic



Year	United States	Japan	Federal Republic of Germany	France	Canada
1976	291	38	20	13	6
1977	363	25	52	11	3
1978	372	34	38	17	1
1979	272	22	30	12	2
1980	386	25	32	20	5
1981	486	42	44	16	6
1982	396	28	43	19	4
1983	466	39	45	30	5
1984	535	49	43	14	10
1985	607	44	47	41	8
1986	663	70	30	30	12
1987	794	86	31	34	14
1988	822	87	33	37	12
1989	1059	138	67	47	13
1990	1113	133	67	58	18
1991	1295	185	59	57	23
1992	1445	225	55	62	24
1993	1632	243	66	65	29
1994	1402	273	46	67	22
1995	1853	362	72	88	37
1996	1866	339	67	73	37
1997	2714	421	95	140	52
1998	3430	525	128	155	84
1999	3710	577	157	194	108
2000	3985	696	151	171	81
2001	4656	746	188	240	120
2002	5104	912	242	236	119
2003	5654	1091	341	228	149
2004	5706	1150	362	179	157
2005	5433	1063	311	210	130
2006	6839	1306	389	238	136

Fig. 5 Country level publication trend analysis of nanotechnology-related patents in USPTO

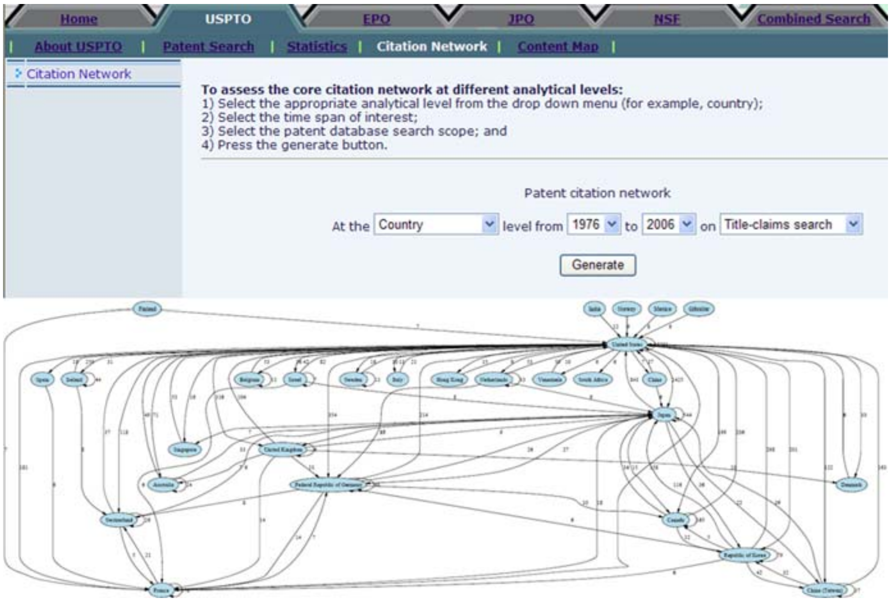


Fig. 6 USPTO country citation network ("title-claims" search, 1976–2006)

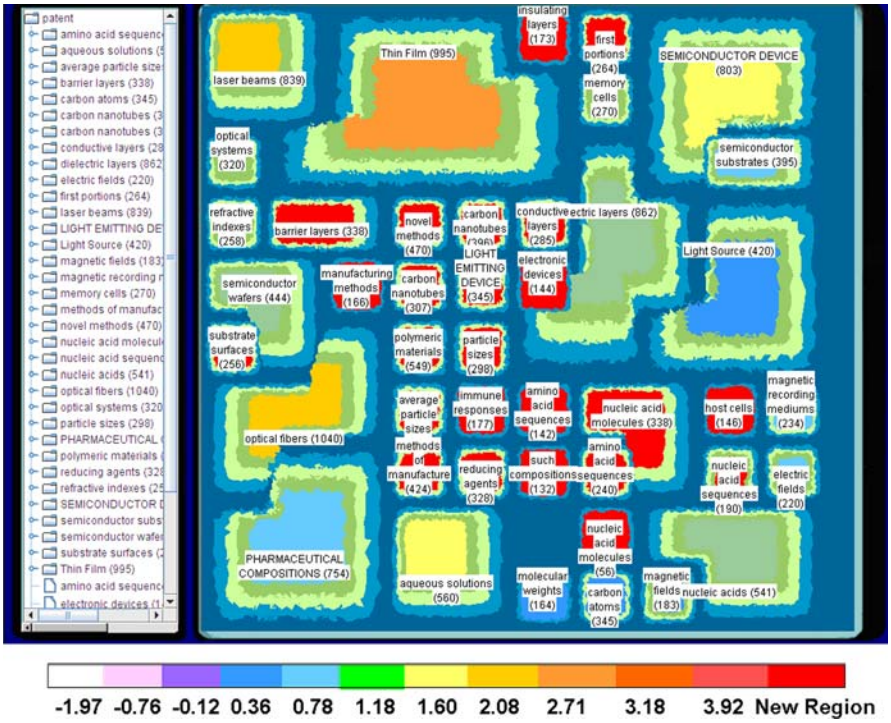


Fig. 7 The content map for topics in USPTO nanotechnology-related patents from 2000 to 2004

region with a 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, respectively (Fig. 7). If the topic is brand new, a red color is assigned to the region.

Nanotechnology development in USPTO (2005–2006)

We use the system outputs from Nano Mapper to assess the nanotechnology development status reflected in USPTO patents between 2005 and

2006. This is a continuation of our previous longitudinal studies (Huang et al. 2003b, 2004, 2006).

In the Nano Mapper database, we collected nanotechnology-related patents issued by the USPTO from 1976 to 2006. For 2005–2006 we collected (see summary in Table 3):

– 2,042 nanotechnology-related patents authored by 4,774 inventors from 874 assignee institutions in 31 countries by using "title-abstract" search.
– 4,081 nanotechnology-related patents invented by 9,491 inventors from 1,585 assignee institutions in 34 countries by using "title-claims" search.
– 18,953 nanotechnology-related patents invented by 40,216 inventors from 5,328 assignee institutions in 49 countries by using "full-text" search.

Figure 8 shows a graph of the annual publications of nanotechnology-related patents in USPTO from 1976 to 2006. Although the three search methods have different coverage, they show a similar growth pattern of nanotechnology development. In 2005–2006, the rapid growth of nanotechnology patent publication continued with some minor fluctuation. The growth rates between 2005 and 2006 were 20–30% using the three search methods.

Country analysis

Tables 4–6 present the 10 most productive nanotechnology assignee countries in the USPTO for 1976–2004 and 2005–2006 using different search methods. In general, the three search methods provide similar results. The United States and Japan continued to be the top 2 countries in 2005–2006. China (Taiwan), Republic of Korea, and Netherlands saw rapid growth. Their ranks rose significantly among all countries. Australia and China entered the top 10 assignee countries lists in 2005–2006, which indicated their rapid growth of nanotechnology innovation.

Tables 7–9 show the countries with a stronger impact on the nanotechnology domain according to the average number of cites per patent they received by December 2006. We include only the countries with a reasonable number of patents for comparison. Although the patents published in 2005–2006 have not received many citations, they still hint at the changes in each country's impact. In general, the United States continued to have a very high impact among other productive countries. In 2005–2006, Australia, China (Taiwan), France, and Netherlands showed an increase in their impacts compared to other countries. Other productive countries, including Japan, Federal Republic of Germany, and Republic of Korea, showed a slight decrease in their impact rankings.

Institution analysis

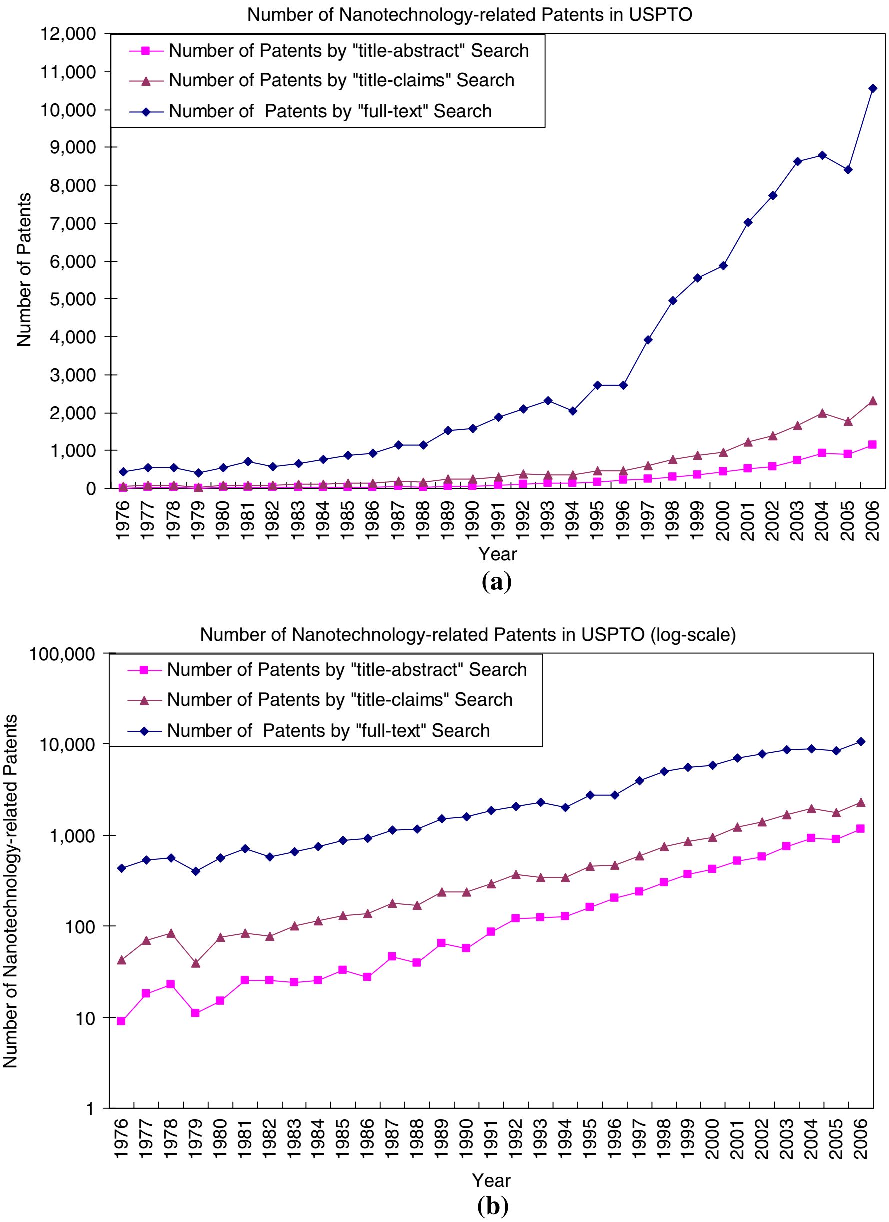
Tables 10–12 show the top 10 assignee institutions that have published the largest number of nanotechnology patents in the USPTO. The three search methods provide slightly different results. However, International Business Machines Corporation, The Regents of the University of California, Eastman Kodak Company, Minnesota Mining and Manufacturing (3M), and Micron Technology, Inc. continued to be the most productive institutions in 2005–2006 as in 1976–2004. Some institutions, including Hewlett-Packard Development Company, Samsung Electronics, and Intel Corporation, had a significant increase in nanotechnology patent publication and became the most productive in the domain.

Tables 13–15 show the top 10 assignees that have high impact on the nanotechnology domain using different types of search in USPTO. We only keep the assignees with a reasonable number of patents. The three search methods provide slightly different results. In general, patents from some famous universities were cited more than others, including patents from the Board of Trustees of the Leland Stanford Junior University, the Regents of the University of California, Massachusetts Institute of Technology, etc. In 2005–2006, some institutions showed a more significant increase in their impact, including Nanosys, Micron Technology, Tsinghua

Table 3 Nanotechnology related patents issued by the USPTO 2005–2006 collected through title-abstract, title-claims, and full-text searches

Search method	Number of nano patents	Number of inventors	Number of institutions	Number of countries
Title-abstract	2,042	4,774	874	31
Title-claims	4,081	9,491	1,585	34
Full-text	18,953	40,216	5,328	49

Fig. 8 Number of nanotechnology patents in USPTO using three types of search methods (1976–2006) (**a**) Normal scale (**b**) Log scale



University, Hitachi, Canon, etc. The Regents of the University of California and Micron Technology produced a large number of high impact patents, which indicates their significant role in nanotechnology.

Technology field analysis

Following our previous research, we used the first-level United States Patent Classification categories (http://www.uspto.gov/go/classification/selectnumwithtitle.htm) as representations of USPTO patents' technology fields.

Tables 16–18 report the top technology fields to which more nanotechnology-related patents were assigned. In general, the three search methods provide similar results. The top technology fields were similar in the two time periods, but their ranks changed. In 2005–2006, technology fields "257: Active solid-state devices," "438:

Table 4 Most productive assignee countries by "title-abstract" patent search (1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004		Patents published in 2005–2006	
	Assignee country	Number of patents	Assignee country	Number of patents
1	United States	3,450	United States	1,322
2	Japan	517	Japan	205
3	Federal Rep. of Germany	204	China (Taiwan)	95
4	France	156	Republic of Korea	89
5	Republic of Korea	131	Federal Republic of Germany	66
6	Canada	104	Canada	34
7	China (Taiwan)	71	France	30
8	United Kingdom	60	Netherlands	22
9	Netherlands	54	China	21
10	Switzerland	41	Israel	14

Table 5 Most productive assignee countries by "title-claims" patent search (1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004		Patents published in 2005–2006	
	Assignee country	Number of patents	Assignee country	Number of patents
1	United States	9,018	United States	2,641
2	Japan	1,113	Japan	373
3	France	482	Federal Republic of Germany	151
4	Federal Republic of Germany	463	China (Taiwan)	147
5	Canada	204	Republic of Korea	137
6	Republic of Korea	194	France	101
7	China (Taiwan)	186	Canada	74
8	United Kingdom	139	Netherlands	52
9	Netherlands	114	United Kingdom	33
10	Switzerland	102	Australia	33

Table 6 Most productive assignee countries by "full-text" patent search (1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004		Patents published in 2005–2006	
	Assignee country	Number of patents	Assignee country	Number of patents
1	United States	53,077	United States	12,272
2	Japan	8,605	Japan	2,369
3	Federal Republic of Germany	2,651	Federal Republic of Germany	700
4	France	2,354	France	448
5	Canada	1,161	China (Taiwan)	382
6	United Kingdom	1,085	Republic of Korea	348
7	China (Taiwan)	547	Netherlands	291
8	Netherlands	546	Canada	266
9	Republic of Korea	535	United Kingdom	198
10	Switzerland	534	Australia	186

Table 7 High impact assignee countries with citations through December 2006 by “title-abstract” search (with >30 patents in 1976–2004 and >10 patents in 2005–2006)

Rank	Patents published in 1976–2004			Patents published in 2005–2006		
	Assignee country	Number of patents	Average number of cites	Assignee country	Number of patents	Average number of cites
1	United States	3,450	3.39	Italy	13	0.15
2	Japan	517	3.04	China	21	0.14
3	Switzerland	41	2.85	United States	1,322	0.14
4	Australia	34	2.85	Netherlands	22	0.14
5	Canada	104	2.31	United Kingdom	13	0.08
6	Republic of Korea	131	2.26	Japan	205	0.07
7	China (Taiwan)	71	1.85	China (Taiwan)	95	0.06
8	Federal Republic of Germany	204	1.61	Republic of Korea	89	0.06
9	France	156	1.53	France	30	0.03
10	United Kingdom	60	0.83	Israel	14	0.00

Table 8 High impact assignee countries with citations through December 2006 by “title-claims” search (with >100 patents in 1976–2004 and >30 patents in 2005–2006)

Rank	Patents published in 1976–2004			Patents published in 2005–2006		
	Assignee country	Number of patents	Average number of cites	Assignee country	Number of patents	Average number of cites
1	United States	9,018	2.34	Australia	33	0.15
2	Japan	1,113	2.08	United States	2,641	0.10
3	Canada	204	2.03	Japan	373	0.09
4	Republic of Korea	194	1.99	China (Taiwan)	147	0.06
5	Switzerland	102	1.95	France	101	0.06
6	United Kingdom	139	1.28	Netherlands	52	0.06
7	China (Taiwan)	186	1.26	Republic of Korea	137	0.04
8	Federal Republic of Germany	463	1.18	Canada	74	0.04
9	France	482	0.91	United Kingdom	33	0.03
10	Netherlands	114	0.62	Federal Republic of Germany	151	0.01

Semiconductor device manufacturing,” and “423: Chemistry of inorganic compounds” experienced faster growth compared with other technology fields.

Tables 19–21 show the high impact nanotechnology fields in the USPTO. For comparison purposes, we use only the technology fields with a reasonable number of patents. The three search methods show slightly different results in the high impact technology fields. However, we notice that the relative impact of technology fields “257: Active solid-state devices (e.g., transistors, solid-state diodes),” “428: Stock material or miscellaneous articles,” and “438: Semiconductor device manufacturing: process” increased in both “title-abstract” search and “title-claims” search. In addition, technology field “423: Chemistry of inorganic compounds” continued to have a high impact on the domain.

Comparing both analyses, we noticed that technology fields 257, 438, and 423, had an increase in both number of patents and number of citations per

Table 9 High impact assignee countries with citations through December 2006 with "full-text" search (with >300 patents in 1976–2004 and >100 patents in 2005–2006)

Rank	Patents published in 1976–2004			Patents published in 2005–2006		
	Assignee country	Number of patents	Average number of cites	Assignee country	Number of patents	Average number of cites
1	United States	53,077	3.17	Australia	186	0.17
2	Israel	346	2.29	United States	12,272	0.11
3	Japan	8,605	2.11	Switzerland	152	0.09
4	Sweden	304	2.02	China (Taiwan)	382	0.09
5	United Kingdom	1,085	2.02	Netherlands	291	0.09
6	Canada	1,161	1.97	Japan	2,369	0.08
7	Switzerland	534	1.93	United Kingdom	198	0.06
8	Netherlands	546	1.87	Federal Republic of Germany	700	0.05
9	Australia	430	1.62	Canada	266	0.05
10	France	2,354	1.53	Republic of Korea	348	0.04

Table 10 Most productive assignees by "title-abstract" patent search (1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004		Patents published in 2005–2006	
	Assignee institution	Number of patents	Assignee institution	Number of patents
1	International Business Machines Corporation	171	The Regents of the University of California	61
2	The Regents of the University of California	123	Hewlett-Packard Development Company, L.P.	40
3	The United States of America as represented by the Secretary of the Navy	82	International Business Machines Corporation	38
4	Eastman Kodak Company	72	William Marsh Rice University	37
5	Minnesota Mining and Manufacturing Company	59	Intel Corporation	36
6	Massachusetts Institute of Technology	56	Samsung Electronics Co. Ltd.	33
7	Xerox Corporation	55	Industrial Technology Research Institute	27
8	Micron Technology, Inc.	53	Micron Technology, Inc.	22
9	Matsushita Electric Industrial Co. Ltd.	45	Nanosys, Inc.	20
10	L'Oreal	44	Massachusetts Institute of Technology	20

patent. These three technology fields have attracted several researchers' interest in recent years.

Conclusions

This paper presents our efforts to create an Internet knowledge mapping system to assess nanotechnology development status based on patent and grant analysis. A research framework and a prototype system, Nano Mapper, are presented for nanotechnology-related patents from USPTO, EPO, and JPO and grants from NSF in the interval 1976–2006. The Nano Mapper provides search functions, statistics, trend analysis, citation network analysis, and content map analysis to assist users' online analysis.

Using Nano Mapper, we evaluated nanotechnology patents published in 2005–2006 by the USPTO and found that:

- Nanotechnology patent publication continues the growth trend seen in previous years with a growth rate of 20–30% between 2005 and 2006.

Table 11 Most productive assignees by "title-claims" patent search (1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004		Patents published in 2005–2006	
	Assignee institution	Number of patents	Assignee institution	Number of patents
1	International Business Machines Corporation	423	Intel Corporation	96
2	Xerox Corporation	226	Micron Technology, Inc.	94
3	The Regents of the University of California	201	International Business Machines Corporation	92
4	Minnesota Mining and Manufacturing Company	195	Hewlett-Packard Development Company, L.P.	81
5	Micron Technology, Inc.	190	The Regents of the University of California	79
6	Eastman Kodak Company	166	General Electric Company	58
7	General Electric Company	150	Samsung Electronics Co. Ltd.	47
8	Motorola, Inc.	149	Eastman Kodak Company	41
9	Advanced Micro Devices, Inc.	147	William Marsh Rice University	37
10	The United States of America as represented by the Secretary of the Navy	138	3M Innovative Properties Company	35

Table 12 Most productive assignees by "full-text" patent search (1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004		Patents published in 2005–2006	
	Assignee institution	Number of patents	Assignee institution	Number of patents
1	International Business Machines Corporation	1,747	Micron Technology, Inc.	411
2	Minnesota Mining and Manufacturing Company	1,138	International Business Machines Corporation	315
3	Xerox Corporation	1,130	Intel Corporation	300
4	The Regents of the University of California	972	Hewlett-Packard Development Company, L.P.	241
5	Eastman Kodak Company	844	The Regents of the University of California	233
6	Micron Technology, Inc.	808	Advanced Micro Devices, Inc.	173
7	Motorola, Inc.	727	Kabushiki Kaisha Toshiba	164
8	General Electric Company	670	3M Innovative Properties Company	161
9	NEC Corporation	634	Canon Kabushiki Kaisha	161
10	Advanced Micro Devices, Inc.	615	Eastman Kodak Company	151

- The United States patents continued to have a high impact on the nanotechnology domain. China (Taiwan), the Republic of Korea, and the Netherlands experienced rapid growth in patent publication in USPTO in 2005–2006. The citation impact of the patents from Australia, China (Taiwan), France, and Netherlands increased significantly.
- In the nanotechnology domain, International Business Machines Corporation, The Regents of the University of California, Eastman Kodak Company, Minnesota Mining and Manufacturing (3M), and Micron Technology, Inc. continued to be among the most productive institutions. Hewlett-Packard Development Company, Samsung Electronics, and Intel Corporation each saw a significant increase in nanotechnology publication. New institutions led by Nanosys, Micron Technology, Tsinghua University, Hitachi, and Canon increased their citation impact in 2005–2006.

Table 13 High impact assignees with citations through December 2006 by "title-abstract" search (with >10 patents in both 1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004			Patents published in 2005–2006		
	Assignee institution	Number of patents	Average number of cites	Assignee institution	Number of patents	Average number of cites
1	President & Fellows of Harvard College	25	14.08	Nanosys, Inc.	20	0.60
2	Hyperion Catalysis International, Inc.	25	13.72	The Board of Trustees of the Leland Stanford Junior University	14	0.50
3	AMCOL International Corporation	22	13.41	Hyperion Catalysis International, Inc.	10	0.40
4	Hewlett-Packard Company	19	11.37	The Regents of the University of California	61	0.34
5	The Board of Trustees of the Leland Stanford Junior University	21	11.05	Nantero, Inc.	19	0.32
6	Digital Instruments, Inc.	24	10.75	Micron Technology, Inc.	22	0.27
7	Regents of the University of Minnesota	10	9.80	Massachusetts Institute of Technology	20	0.20
8	Nanosphere, Inc.	24	9.25	Tsinghua University	11	0.18
9	The Penn State Research Foundation	18	9.06	Freescale Semiconductor, Inc.	12	0.17
10	Olympus Optical Co. Ltd.	15	9.00	Hitachi, Ltd.	12	0.17

Table 14 High impact assignees with citations through December 2006 by "title-claims" search (with >20 patents in both 1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004			Patents published in 2005–2006		
	Assignee institution	Number of patents	Average number of cites	Assignee institution	Number of patents	Average number of cites
1	President & Fellows of Harvard College	27	17.07	Nanosys, Inc.	20	0.60
2	AMCOL International Corporation	22	14.27	The Regents of the University of California	79	0.27
3	Digital Instruments, Inc.	28	13.14	Micron Technology, Inc.	94	0.23
4	Hyperion Catalysis International, Inc.	47	12.64	Advanced Micro Devices, Inc.	32	0.22
5	Transitions Optical, Inc.	28	9.57	Canon Kabushiki Kaisha	33	0.18
6	Nanosphere, Inc.	24	9.42	Massachusetts Institute of Technology	35	0.17
7	Olympus Optical Co. Ltd.	25	7.56	Industrial Technology Research Institute	34	0.15
8	The Penn State Research Foundation	24	7.25	Xerox Corporation	30	0.13
9	The Regents of the University of California	201	6.21	Sharp Laboratories of America, Inc.	33	0.12
10	Massachusetts Institute of Technology	105	5.97	Hitachi, Ltd.	27	0.11

Table 15 High impact assignees with citations through December 2006 by "full-text" search (with >50 patents in both 1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004			Patents published in 2005–2006		
	Assignee institution	Number of patents	Average number of cites	Assignee institution	Number of patents	Average number of cites
1	Hyperion Catalysis International, Inc.	54	15.50	Board of Regents, The University of Texas System	53	0.36
2	Nanogen, Inc.	61	13.56	Micron Technology, Inc.	411	0.34
3	President & Fellows of Harvard College	83	13.14	Massachusetts Institute of Technology	96	0.30
4	Emisphere Technologies, Inc.	59	11.24	California Institute of Technology	73	0.30
5	Affymetrix, Inc.	71	9.08	Advanced Micro Devices, Inc.	173	0.23
6	The Board of Trustees of the Leland Stanford Junior University	133	8.65	Silverbrook Research Pty Ltd.	137	0.20
7	Cornell Research Foundation, Inc.	127	7.44	Sony Corporation	117	0.18
8	Massachusetts Institute of Technology	355	7.35	Applied Materials, Inc.	124	0.18
9	Agere Systems Guardian Corp.	50	7.02	Hitachi Global Storage Technologies Netherlands B.V.	63	0.16
10	PPG Industries, Inc.	252	6.41	Taiwan Semiconductor Manufacturing Company, Ltd.	54	0.15

Table 16 Most productive technology fields by "title-abstract" patent search (1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004		Patents published in 2005–2006	
	Technology field	Number of patents	Technology field	Number of patents
1	428: Stock material or miscellaneous articles	621	257: Active solid-state devices	392
2	257: Active solid-state devices	518	438: Semiconductor device manufacturing	293
3	427: Coating processes	506	428: Stock material or miscellaneous articles	264
4	438: Semiconductor device manufacturing	503	423: Chemistry of inorganic compounds	208
5	250: Radiant energy	465	427: Coating processes	144
6	424: Drug, bio-affecting and body treating compositions	434	250: Radiant energy	96
7	423: Chemistry of inorganic compounds	379	524: Synthetic resins or natural rubbers	93
8	435: Chemistry: molecular biology and microbiology	289	424: Drug, bio-affecting and body treating compositions	89
9	524: Synthetic resins or natural rubbers	243	435: Chemistry: molecular biology and microbiology	85
10	073: Measuring and testing	224	252: Compositions	81

- In 2005–2006, there was rapid growth in patent publication in technology fields "257: Active solid-state devices," "438: Semiconductor device manufacturing," and "423: Chemistry of inorganic compounds" as compared with other technology fields. The impact of the patents in technology fields "257: Active solid-state devices (e.g., transistors, solid-state diodes)," "428: Stock material or miscellaneous articles," and "438: Semiconductor device manufacturing: process"

Table 17 Most productive technology fields by "title-claims" patent search (1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004		Patents published in 2005–2006	
	Technology field	Number of patents	Technology field	Number of patents
1	428: Stock material or miscellaneous articles	1,300	257: Active solid-state devices	814
2	257: Active solid-state devices	1,294	438: Semiconductor device manufacturing	590
3	438: Semiconductor device manufacturing	1,281	428: Stock material or miscellaneous articles	427
4	250: Radiant energy	1,128	423: Chemistry of inorganic compounds	245
5	427: Coating processes	1,029	427: Coating processes	236
6	424: Drug, bio-affecting and body treating compositions	935	250: Radiant energy	202
7	435: Chemistry: molecular biology and microbiology	733	435: Chemistry: molecular biology and microbiology	178
8	430: Radiation imagery chemistry: process, composition	695	359: Optics: systems	171
9	359: Optics: systems	661	424: Drug, bio-affecting and body treating compositions	167
10	514: Drug, bio-affecting and body treating compositions	644	430: Radiation imagery chemistry: process	156

Table 18 Most productive technology fields by "full-text" patent search (1976–2004 and 2005–2006)

Rank	Patents published in 1976–2004		Patents published in 2005–2006	
	Technology field	Number of patents	Technology field	Number of patents
1	435: Chemistry: molecular biology and microbiology	9,793	257: Active solid-state devices	2,828
2	514: Drug, bio-affecting and body treating compositions	7,760	438: Semiconductor device manufacturing	2,155
3	424: Drug, bio-affecting and body treating compositions	5,999	435: Chemistry: molecular biology and microbiology	1,993
4	257: Active solid-state devices	5,610	514: Drug, bio-affecting and body treating compositions	1,307
5	438: Semiconductor device manufacturing: process	5,387	428: Stock material or miscellaneous articles	1,175
6	428: Stock material or miscellaneous articles	5,101	424: Drug, bio-affecting and body treating compositions	1,162
7	536: Organic compounds—part of the class 532–570 series	4,729	530: Chemistry: natural resins or derivatives	1,018
8	530: Chemistry: natural resins or derivatives	4,655	536: Organic compounds—part of the class 532–570 series	973
9	250: Radiant energy	4,635	250: Radiant energy	903
10	427: Coating processes	4,034	359: Optics: systems	822

also increased during the same time period. Technology field "423: Chemistry of inorganic compounds" continued to have a strong impact on the nanotechnology domain.

The Nano Mapper system provides a search and analysis infrastructure for researchers and policy makers. In our future research, we plan to annually update the data sets in the system. We will

Table 19 High impact technology fields with citations through December 2006 by "title-abstract" patent search (with >50 patents in 1976–2004 and >30 patents in 2005–2006)

Rank	Patents published in 1976–2004			Patents published in 2005–2006		
	Technology field	Number of patents	Average number of cites	Technology field	Number of patents	Average number of cites
1	445: Electric lamp or space discharge component or device manufacturing	65	7.65	117: Single-crystal, oriented-crystal, and epitaxy growth processes; non-coating apparatus therefor	32	0.28
2	117: Single-crystal, oriented-crystal, and epitaxy growth processes; non-coating apparatus therefor	72	6.60	257: Active solid-state devices (e.g., transistors, solid-state diodes)	392	0.18
3	423: Chemistry of inorganic compounds	379	6.13	423: Chemistry of inorganic compounds	208	0.16
4	365: Static information storage and retrieval	80	5.44	428: Stock material or miscellaneous articles	264	0.16
5	250: Radiant energy	465	5.09	264: Plastic and nonmetallic article shaping or treating: processes	70	0.16
6	313: Electric lamp and discharge devices	172	4.73	313: Electric lamp and discharge devices	79	0.15
7	205: Electrolysis: processes, compositions used therein, and methods of preparing the compositions	88	4.63	204: Chemistry: electrical and wave energy	47	0.15
8	422: Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing	148	4.17	438: Semiconductor device manufacturing: process	293	0.14
9	369: Dynamic information storage or retrieval	66	4.14	106: Compositions: coating or plastic	43	0.14
10	436: Chemistry: analytical and immunological testing	179	4.12	436: Chemistry: analytical and immunological testing	42	0.12

Table 20 High impact technology fields with citations through December 2006 by "full-text" patent search (with >100 patents in 1976–2004 and >50 patents in 2005–2006)

Rank	Patents published in 1976–2004			Patents published in 2005–2006		
	Technology field	Number of patents	Average number of cites	Technology field	Number of patents	Average number of cites
1	423: Chemistry of inorganic compounds	544	5.23	445: Electric lamp or space discharge component or device manufacturing	61	0.18
2	117: Single-crystal, oriented-crystal, and epitaxy growth processes; non-coating apparatus therefor	117	5.14	423: Chemistry of inorganic compounds	245	0.16
3	365: Static information storage and retrieval	200	4.32	257: Active solid-state devices (e.g., transistors, solid-state diodes)	814	0.16
4	075: Specialized metallurgical processes, compositions for use therein, consolidated metal powder compositions, and loose metal particulate mixtures	154	4.04	365: Static information storage and retrieval	92	0.15
5	313: Electric lamp and discharge devices	384	3.74	204: Chemistry: electrical and wave energy	85	0.14
6	250: Radiant energy	1128	3.54	313: Electric lamp and discharge devices	146	0.14
7	369: Dynamic information storage or retrieval	148	3.53	438: Semiconductor device manufacturing: process	590	0.13
8	549: Organic compounds—part of the class 532–570 series	100	3.50	372: Coherent light generators	66	0.12
9	073: Measuring and testing	355	3.38	428: Stock material or miscellaneous articles	427	0.12
10	523: Synthetic resins or natural rubbers—part of the class 520 series	240	3.33	264: Plastic and nonmetallic article shaping or treating: processes	126	0.11

Table 21 High impact technology fields with citations through December 2006 by "full-text" search (with >200 patents in 1976–2004 and >100 patents in 2005–2006)

Rank	Patents published in 1976–2004			Patents published in 2005–2006		
	Technology field	Number of patents	Average number of cites	Technology field	Number of patents	Average number of cites
1	051: Abrasive tool making process, material, or composition	282	6.77	345: Computer graphics processing, operator interface processing, and selective visual display systems	169	0.41
2	445: Electric lamp or space discharge component or device manufacturing	294	5.87	365: Static information storage and retrieval	451	0.24
3	365: Static information storage and retrieval	1,125	5.49	451: Abrading	163	0.22
4	216: Etching a substrate: processes	1,034	5.38	204: Chemistry: electrical and wave energy	338	0.20
5	117: Single-crystal, oriented-crystal, and epitaxy growth processes; non-coating apparatus therefor	470	5.27	359: Optics: systems (including communication) and elements	822	0.19
6	422: Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing	2,117	4.97	355: Photocopying	181	0.16
7	250: Radiant energy	4,635	4.89	205: Electrolysis: processes, compositions used therein, and methods of preparing the compositions	140	0.16
8	436: Chemistry: analytical and immunological testing	3,523	4.82	257: Active solid-state devices (e.g., transistors, solid-state diodes)	2,828	0.16
9	606: Surgery	622	4.65	310: Electrical generator or motor structure	169	0.15
10	523: Synthetic resins or natural rubbers—part of the class 520 series	887	4.49	106: Compositions: coating or plastic	195	0.15

incorporate other types of scientific documents into our framework and introduce additional analytical and visualization methods.

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