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# Longitudinal patent analysis for nanoscale science and engineering: Country, institution and technology field

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## Abstract

Nanoscale science and engineering (NSE) and related areas have seen rapid growth in recent years. The speed and scope of development in the field have made it essential for researchers to be informed on the progress across different laboratories, companies, industries and countries. In this project, we experimented with several analysis and visualization techniques on NSE-related United States patent documents to support various knowledge tasks. This paper presents results on the basic analysis of nanotechnology patents between 1976 and 2002, content map analysis and citation network analysis. The data have been obtained on individual countries, institutions and technology fields. The top 10 countries with the largest number of nanotechnology patents are the United States, Japan, France, the United Kingdom, Taiwan, Korea, the Netherlands, Switzerland, Italy and Australia. The fastest growth in the last 5 years has been in chemical and pharmaceutical fields, followed by semiconductor devices. The results demonstrate potential of information-based discovery and visualization technologies to capture knowledge regarding nanotechnology performance, transfer of knowledge and trends of development through analyzing the patent documents.

## Introduction

Recent rapid development of Nanoscale Science and Engineering (NSE) promises to bring fundamental changes to a wide range of research fields and industries. NSE has been recognized to be critical to a country's future science and technology competence and has recently attracted global research and development interests. The United States has announced the National Nanotechnology Initiative (NNI) in 2000 based on a long-term vision (Roco et al., 2000). More than 30 countries have adopted national projects or programs partially stimulated by NNI (Roco, 2002). Both long-term basic research and short-term development related to nanotechnology are being actively explored across many scientific fields and industrial applications. The speed and scope of nanotechnology development make it critical for researchers to be aware of publications and patents in the field across different laboratories, companies, industries and countries.

A patent is a special type of technology document. As an open source of knowledge, it contains rich content regarding technology innovations and is accessible by the general public. Most countries have adopted similar patent systems. A large number of patents are issued everyday and collected and published systematically worldwide. For example, US Patent and Trademark Office (USPTO) has in total more than 5 million patents, with 3500 to 4000 newly granted patents being added into the database each week. As a result, collections of full-text patents over a long period of time (typically 20–30 years) are available. The patent documents are also strictly structured, providing standardized fields such as patent citation, issue date, assignee (the institution to which the patent is assigned to), inventors, technology field classification, and country and city of the assignee and inventors, etc. All these special features of patent documents make them a valuable source of knowledge regarding technology development.

We aim to leverage various information analysis and visualization technologies to support domain-specific knowledge discovery from patent documents. The proposed framework is targeted at supporting high-level knowledge tasks (e.g. country-level technology strength comparison, new research field identification, etc.). Such knowledge is typically obtained by extensive literature searches that require large amounts of time, resources and human efforts. An automatic patent analysis framework has the potential to alleviate the information overload problem faced by the researchers in the NSE field.

There is a substantial academic literature and many industrial practices of using patent analysis for technology strength and trend evaluation (Garfield, 1955; Karki, 1997; Oppenheim, 2000). However, building an automatic patent analysis service for the NSE is still a challenging task. The difficulties are: (1) uncertainty of the validity of using patent data to approximate the science and technology development in NSE; (2) difficulty of intuitive presentation of analysis results, such as identification of fast-evolving (obsolescing) subcategories and new concepts; and (3) terminology/naming differences that are inherent in the patent data. Our goal is to build a prototype system to examine both technical issues and fundamental hypotheses involved with knowledge discovery through patent analysis.

A smaller scale survey of the USPTO database that surveyed 2600 patents was run by M. Meyer (see Roco & Bainbridge, 2001, pp. 296–311). The reviewed patents had the dominant focus on instruments, electronics and chemical/pharmaceutics. Another observation was that only about 1% of them were referred in the Science Citation Index publication on NSE in the same time period.

In the absence of a unified global patent system, as proposed recently (Schwartz, 2003), the USPTO database is the most representative because usually the claims submitted in other countries are simultaneously submitted to USPTO. Besides the international recognition, this is done in order to assure the patent protection in the largest commercial market in the world.

In this paper, we describe the overall research design of patent analysis for NSE and present current testbed

*Table 1.* Nanoscale science and engineering keyword list

| Terms | Number of documents |
|---|---|
| Selfassembl* | 18 |
| Self assembl* | 5613 |
| Atomic force microscop* | 2941 |
| Atomic-force-microscop* | 4 |
| Scanning tunneling microscop* | 1674 |
| Scanning-tunneling-microscop* | 25 |
| Atomistic simulation | 5 |
| Biomotor | 4 |
| Molecular device | 104 |
| Molecular electronics | 199 |
| Molecular modeling | 1336 |
| Molecular motor | 59 |
| Molecular sensor | 17 |
| Molecular simulation | 33 |
| Quantum computing | 25 |
| Quantum dot* | 352 |
| Quantum effect* | 467 |
| Nano* | 76277 |
| Total | 89,153 |
| Actual collected | 88,546 |
| Collection coverage | 99.32% |

*Note*: A patent document may contain multiple key phrases listed in the table, thus the total number of unique patent documents was smaller than the total number of collected patent documents presented in the table.
* Serves as a wildcard, e.g. 'nano' refers to words that start with 'nano'.

*Table 2.* Assignee country analysis (1976–2002)

| Rank | Assignee country | Number of patents |
|---|---|---|
| 1 | United States | 56,828 |
| 2 | Japan | 7574 |
| 3 | France | 2087 |
| 4 | United Kingdom | 871 |
| 5 | Switzerland | 419 |
| 6 | China (Taiwan) | 382 |
| 7 | Italy | 377 |
| 8 | Republic of Korea | 368 |
| 9 | the Netherlands | 308 |
| 10 | Australia | 307 |
| 11 | Sweden | 264 |
| 12 | Belgium | 193 |
| 13 | Finland | 125 |
| 14 | Denmark | 104 |

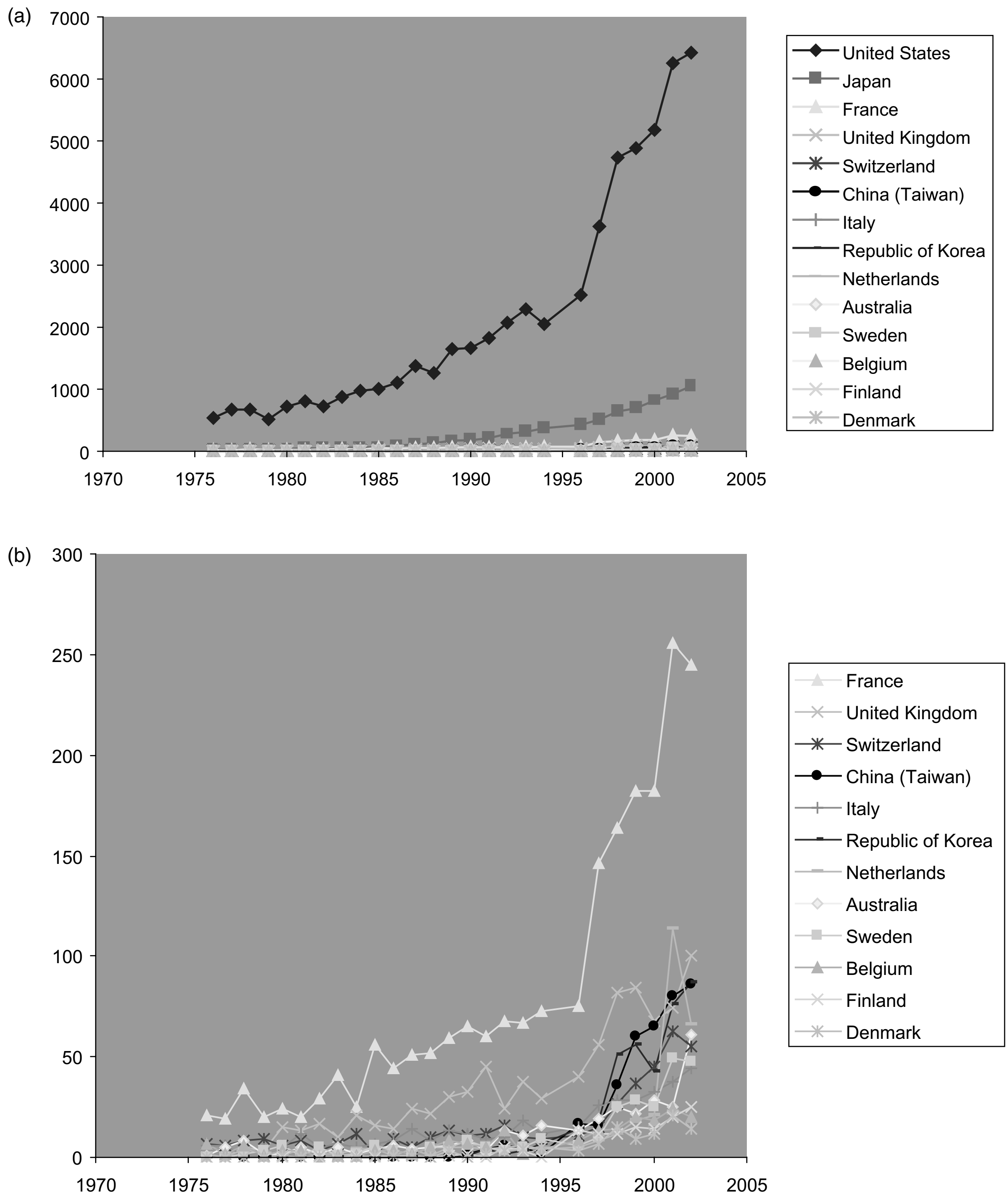


*Figure 1.* Number of nanotechnology patents per country by year: (a) for 14 leading countries; (b) without United States and Japan.

*Table 3*. Number of patents of assignee countries by year

| Year | United States | Japan | France | United Kingdom | Switzerland | China (Taiwan) | Italy | Republic of Korea | Netherlands | Australia |
|---|---|---|---|---|---|---|---|---|---|---|
| 1976 | 538 | 40 | 21 | 0 | 7 | 0 | 6 | 0 | 2 | 1 |
| 1977 | 670 | 21 | 19 | 0 | 6 | 0 | 6 | 0 | 0 | 5 |
| 1978 | 670 | 36 | 34 | 5 | 8 | 0 | 1 | 0 | 4 | 8 |
| 1979 | 516 | 27 | 20 | 3 | 9 | 0 | 4 | 0 | 2 | 2 |
| 1980 | 718 | 39 | 24 | 15 | 6 | 0 | 5 | 0 | 1 | 2 |
| 1981 | 806 | 53 | 20 | 13 | 8 | 0 | 12 | 0 | 4 | 5 |
| 1982 | 724 | 43 | 29 | 17 | 3 | 0 | 5 | 0 | 2 | 2 |
| 1983 | 874 | 57 | 41 | 10 | 7 | 0 | 7 | 0 | 2 | 5 |
| 1984 | 975 | 65 | 25 | 21 | 12 | 0 | 5 | 0 | 4 | 2 |
| 1985 | 1005 | 64 | 56 | 16 | 2 | 0 | 7 | 0 | 4 | 4 |
| 1986 | 1104 | 93 | 44 | 14 | 9 | 0 | 8 | 0 | 1 | 6 |
| 1987 | 1376 | 112 | 51 | 24 | 5 | 0 | 14 | 0 | 4 | 4 |
| 1988 | 1263 | 129 | 52 | 22 | 10 | 0 | 8 | 0 | 1 | 5 |
| 1989 | 1647 | 172 | 59 | 30 | 13 | 0 | 13 | 0 | 5 | 6 |
| 1990 | 1666 | 179 | 65 | 33 | 11 | 2 | 12 | 1 | 5 | 8 |
| 1991 | 1824 | 214 | 60 | 45 | 12 | 4 | 9 | 4 | 4 | 3 |
| 1992 | 2072 | 280 | 68 | 24 | 16 | 6 | 10 | 2 | 5 | 13 |
| 1993 | 2289 | 312 | 67 | 38 | 10 | 5 | 18 | 3 | 6 | 11 |
| 1994 | 2049 | 373 | 73 | 29 | 9 | 2 | 12 | 7 | 4 | 16 |
| 1996 | 2519 | 423 | 75 | 40 | 11 | 17 | 15 | 14 | 5 | 13 |
| 1997 | 3623 | 513 | 146 | 56 | 15 | 16 | 26 | 18 | 8 | 19 |
| 1998 | 4731 | 643 | 164 | 82 | 27 | 36 | 28 | 51 | 12 | 25 |
| 1999 | 4883 | 694 | 182 | 84 | 37 | 60 | 28 | 56 | 18 | 22 |
| 2000 | 5181 | 820 | 182 | 68 | 45 | 65 | 33 | 43 | 21 | 28 |
| 2001 | 6254 | 923 | 256 | 74 | 63 | 80 | 38 | 76 | 114 | 25 |
| 2002 | 6425 | 1050 | 245 | 100 | 55 | 86 | 44 | 87 | 66 | 61 |

and initial analysis results. We include data and visualization results of three types of analyses (basic analysis, content map analysis and citation network analysis) for three analytical units (countries, institutions and technology fields).

*Table 4*. Assignee country group analysis (1976–2002)

| Country group | Number of patents | Cites per patent |
|---|---|---|
| US | 56,828 | 3.95 |
| JP | 7574 | 3.28 |
| EC | 4046 | 3.09 |
| Others | 2241 | 2.65 |

## Research design

The overall research objective is to develop a generic patent analysis framework for knowledge discovery on technology development of fast-evolving scientific domains. We aim to support different levels of analysis (country, industry, company, etc.) for customizable technology subjects (e.g. all NSE-related patents or subcategories of NSE-related patents). Another important component of the project is application of large-scale information visualization research (Chen et al., 1998, 1996) to achieve intuitive presentation of patent analysis results. This prototype framework will also serve as a testbed to evaluate the validity, values and limitations of patent analysis in discovering knowledge of science and technology development.

The patent analysis framework contains the following major elements.

### *Analytical units*

Numerous analytical units have been used in the patent analysis literature. Some common units are countries, industries and companies. In order to make the analysis framework generic, we propose a system of analytical units in order to separate generic analysis techniques from contextual information. For example, techniques used for technology performance evaluation at the country level and the industry level should be largely applicable to other analytical units such as regions and companies. Our proposed analytical units include: geographical regions (e.g. countries, regions, states, cities, etc.); industries/research fields (e.g. NSE, genetics, semiconductor, etc.); sectors (e.g. private companies, government organizations, academic institutions, etc.); institutions (e.g. companies, universities, research labs, etc.); individuals; and cross-units (e.g. industries within geographic regions; technology fields within institutions; institutions within industries, etc.)

*Analysis types*

Previous patent analyses can be grouped into three categories:

*Performance evaluation.* This analysis type seeks to evaluate an analytical unit's performance in technology development based on patent-based quantity and quality measures. The quantity measures indicate the patenting activity level of an analytical unit (e.g. the

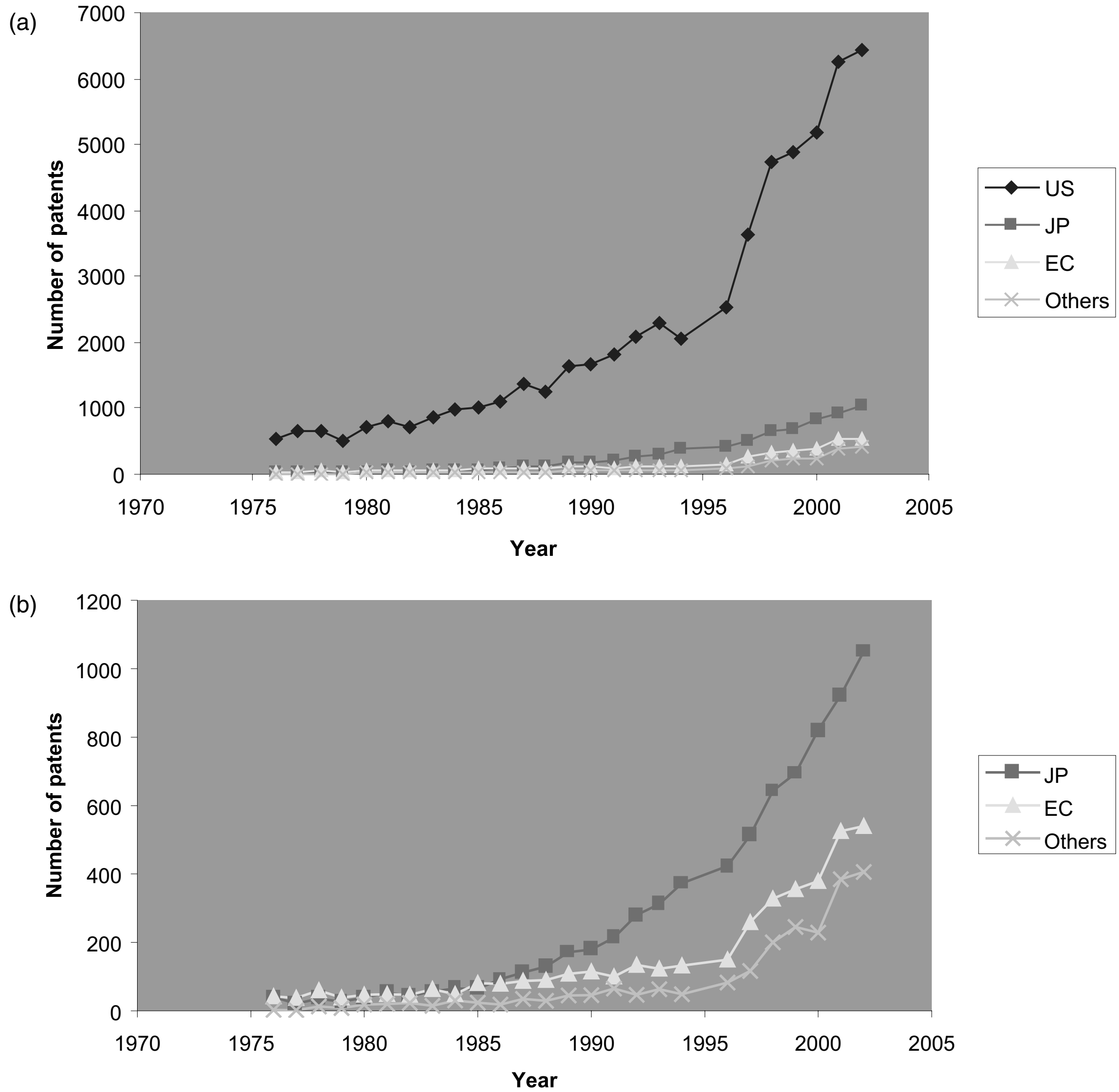


*Figure 2.* Assignee country group analysis by years: (a) for 14 leading countries; (b) without the United States and Japan.

*Table 5.* Assignee analysis (1976–2002)

| Rank | Assignee name | Number of patents | Average patent age |
|---|---|---|---|
| 1 | International Business Machines Corporation | 2092 | 6.6 |
| 2 | Xerox Corporation | 1039 | 7.1 |
| 3 | Minnesota Mining and Manufacturing Company (3M) | 809 | 6.9 |
| 4 | Micron Technology, Inc. | 781 | 1.9 |
| 5 | Eastman Kodak Company | 738 | 9.3 |
| 6 | Motorola, Inc. | 705 | 7.1 |
| 7 | Texas Instruments Incorporated | 694 | 6.9 |
| 8 | NEC Corporation | 608 | 3.7 |
| 9 | The Regents of the University of California | 540 | 3 |
| 11 | The United States of America as represented by the Secretary of the Navy | 525 | 10 |
| 12 | Canon Kabushiki Kaisha | 505 | 5 |
| 13 | Advanced Micro Devices, Inc. | 502 | 3.3 |
| 14 | General Electric Company | 491 | 11 |
| 15 | Hitachi, Ltd. | 462 | 5.7 |
| 16 | Hewlett-Packard Company | 434 | 7.7 |
| 17 | Kabushiki Kaisha Toshiba | 412 | 4.6 |
| 18 | E. I. DuPont de Nemours and Company | 362 | 11 |
| 18 | Lucent Technologies Inc. | 341 | 2.8 |
| 19 | Intel Corporation | 341 | 4.6 |
| 20 | The Dow Chemical Company | 322 | 10 |

number of patents, patent growth rate and market percentage measures). The quality measures are mainly based on the citation information. Many citation-based indicators developed in the field can be used to estimate the impact of patents, cycle time of development, science linkage and other important characteristics. Based on these indicators, different aspects of the analytical unit can be computed to obtain a comprehensive picture of technology development performance.

*Transfer of knowledge.* Typical knowledge transfer analysis of patents has focused on the knowledge flow from science literature to patents (Schmoch, 1993). We generalize the classic knowledge transfer analysis to analyze the knowledge flow among any analytical units. For example, we can analyze the knowledge transfer between countries, sectors, companies, etc. Such analysis will result in a multi-level knowledge transfer network, and network analysis techniques can be applied to discover interesting patterns. Both patent citations and journal citations will be used for the construction of the knowledge transfer network. Analytical units from the scientific research community, such as journals, universities, research labs, etc., will also enter the landscape of the network.

*Trend analysis.* Technology trend analysis is mainly derived from the citation network of patents. The main objective is to use the citation structures together with other indicators such as patent cycle time, number of patents, number of applicants, etc. to construct a history of the technology development of certain analytical units. With such analysis, users can identify an analytical unit's major technology innovation fields, key changing points of technology fields, life cycles of technology fields, emerging developing fields, etc.

*Visualization*

Many ideas for visualizing patent data have been proposed in the literature and practiced in the industry. The seminal work is Garfield's Citation Networks (Garfield, 1979), in which a network display was first used to visualize the relationships among a set of patents. Subsequent research has applied different visualization techniques on citation networks, including the 'Butterfly' display (Mackinlay et al., 1999), hyperbolic tree display (Aureka, 2002), clustering display based on co-citation (Small, 1999) and Pathfinder network displays (Chen & Paul, 2001). However, most visualization research and practice has been confined to raw-data visualization such as the patent citation network structure display and plots of patent indicators. In this project, we leverage our experience to build a visual environment that integrates multiple layers of information, including raw patent data and analysis results mentioned previously. There are many open issues in this area, and many of the factors that determine the effectiveness of patent analysis results on visualization are uncertain. This proposed research prototype should provide an ideal testbed to explore these uncertainties.

This paper presents initial results of basic analysis, content map analysis and citation network analysis to demonstrate performance evaluation, knowledge transfer analysis and trend analysis based on patent documents. The reported results cover three analytical units: countries, institutions and technology fields. Several visualization technologies are also applied to present the analysis results.

## Data description

The test data set of nanotechnology-related patents was collected from the USPTO's patent database. We have

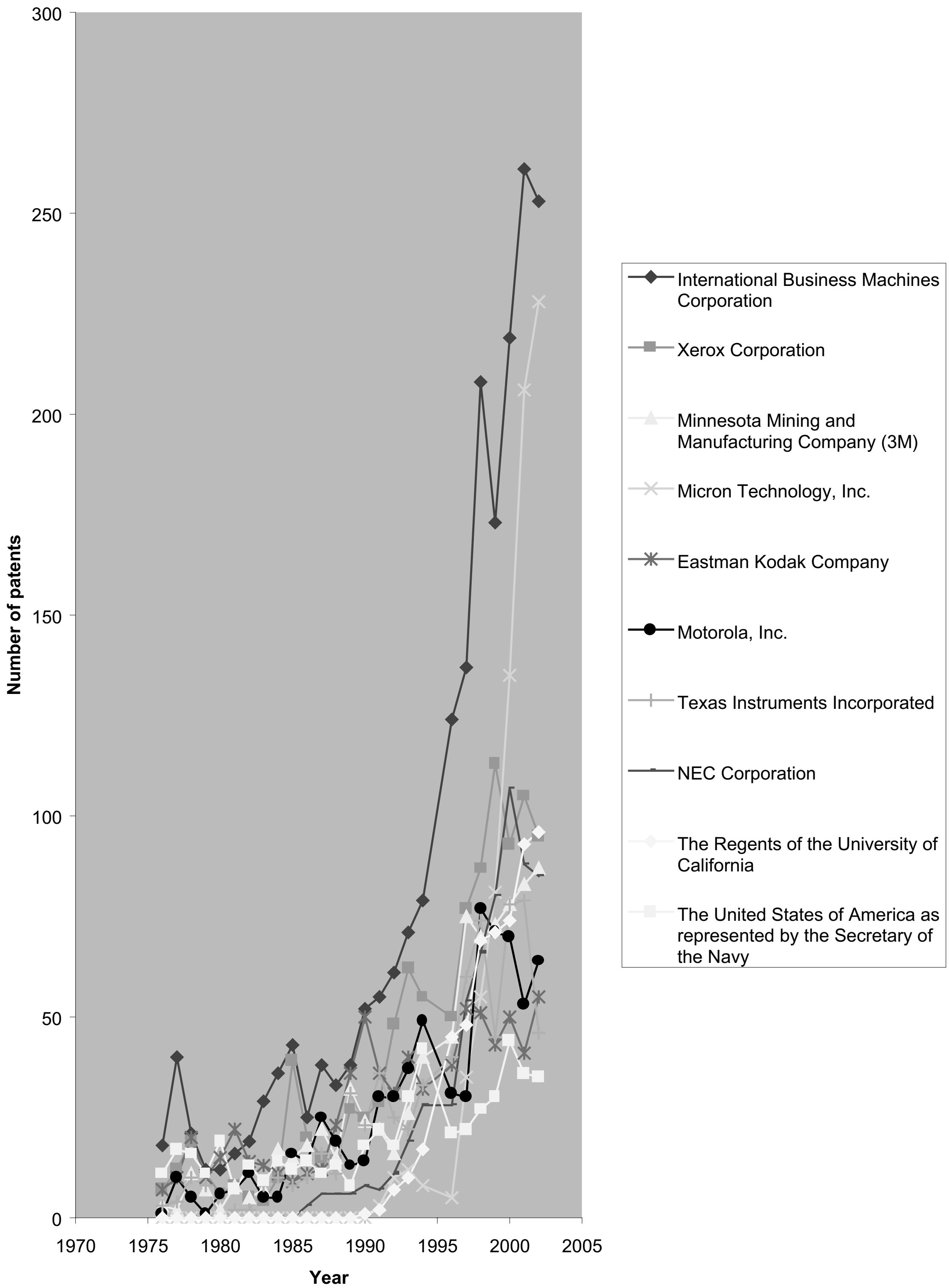


*Figure 3*. Assignee analysis by year between 1976 and 2002.

*Table 6.* Cites per patent by assignee (1976–2002)

| Assignee name | Cites per patent |
|---|---|
| Minnesota Mining and Manufacturing Company | 6.4 |
| The Dow Chemical Company | 6.1 |
| California Institute of Technology | 6.1 |
| Xerox Corporation | 5.2 |
| Genentech, Inc. | 4.9 |
| PPG Industries, Inc. | 4.9 |
| E. I. DuPont de Nemours and Company | 4.8 |
| International Business Machines Corporation | 4.7 |
| AT&T Bell Laboratories | 4.6 |
| Micron Technology, Inc. | 4.4 |

*Table 7.* Technology independence analysis (1976–2002)

| Assignee name | Technology independence |
|---|---|
| Smithkline Beecham Corporation | 0.7 |
| Merck & Co., Inc. | 0.3 |
| Bell Telephone Laboratories, Incorporated | 0.3 |
| The United States of America as represented by the Secretary of the Army | 0.3 |
| Abbott Laboratories | 0.2 |
| The United States of America as represented by the United States | 0.2 |
| AT&T Bell Laboratories | 0.2 |
| The United States of America as represented by the Secretary of the Air | 0.2 |
| Lucent Technologies Inc. | 0.2 |
| Hughes Aircraft Company | 0.2 |

used a keyword-based approach to select a subset of the US nanotechnology-related patents available online from 1976 to 2002. The US patents prior to 1976 do not have full-text access. The data were collected in March 2003 and it is expected that a fraction of the 2002 patents were not yet available.

We used nanotechnology terms adopted in previous NSF database searches for the NSE field (Table 1). There are 89,153 patents in the USPTO database that contain such keywords and we have successfully collected 88,546 of them (99.32%). Most patents were collected by using the 'nano*' keyword, which referred to any term starting with 'nano'. We also filtered out patents that contained only 'nanosecond' or 'nanoliter' but not any other words starting with 'nano'.

There are 69,927 assignees, 123,752 inventors and 228 countries involved with the 77,605 unique patents in our data set. These patents cover 418 of 462 first-level US Patent Classification categories. Examples of such

*Table 8.* Technology cycle time by assignee (1976–2002)

| Assignee name | Technology cycle time |
|---|---|
| Advanced Micro Devices, Inc. | 2 |
| Applied Materials, Inc. | 2 |
| 3M Innovative Properties Company | 2 |
| Micron Technology, Inc. | 2 |
| Smithkline Beecham Corporation | 3 |
| Lucent Technologies Inc. | 4 |
| The Regents of the University of California | 4 |
| California Institute of Technology | 4 |
| Intel Corporation | 4 |
| Kabushiki Kaisha Toshiba | 4 |
| LSI Logic Corporation | 4 |
| L'Oreal | 4 |
| NEC Corporation | 4 |
| Genentech, Inc. | 5 |
| International Business Machines Corporation | 5 |
| Hitachi, Ltd. | 5 |
| Canon Kabushiki Kaisha | 5 |
| Sony Corporation | 5 |
| Mitsubishi Denki Kabushiki Kaisha | 5 |
| Fujitsu Limited | 5 |

*Table 9.* Science linkage by assignee (1976–2002)

| Assignee name | Science linkage |
|---|---|
| Genentech, Inc. | 63 |
| California Institute of Technology | 55 |
| The Regents of the University of California | 28 |
| Massachusetts Institute of Technology | 25 |
| Micron Technology, Inc. | 19 |
| Merck & Co., Inc. | 14 |
| Eli Lilly and Company | 14 |
| Abbott Laboratories | 11 |
| LSI Logic Corporation | 9 |
| The Dow Chemical Company | 9 |

categories are 'organic compounds – part of the class 532–570 series', 'drug, bio-affecting and body treating compositions', 'chemistry: molecular biology and microbiology', etc. Currently we treat such classification categories as technology fields. The analytical units used in our analyses mainly relate to the countries, assignees, and technology fields.

## Basic analysis

Basic analysis refers to the traditional patent analysis that has been widely applied in technology

*Table 10.* Number of patents of technology fields (1976–2002)

| Field name | Number of patents |
|---|---|
| Chemistry: molecular biology and microbiology | 7946 |
| Drug, bio-affecting and body treating compositions (CCL-514) | 6183 |
| Drug, bio-affecting and body treating compositions (CCL-424) | 4683 |
| Radiant energy | 4657 |
| Stock material or miscellaneous articles | 3939 |
| Active solid-state devices (e.g. transistors, solid-state diodes) | 3933 |
| Semiconductor device manufacturing: process | 3877 |
| Organic compounds – part of the class 532–570 series | 3756 |
| Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof | 3753 |
| Optics: systems (including communication) and elements | 3404 |
| Coating processes | 3265 |
| Chemistry: analytical and immunological testing | 3027 |
| Radiation imagery chemistry: process, composition, or product thereof | 2983 |
| Optics: measuring and testing | 2957 |
| Static information storage and retrieval | 2310 |
| Miscellaneous active electrical nonlinear devices, circuits, and systems | 2286 |
| Chemistry: electrical and wave energy | 1864 |
| Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing | 1829 |
| Coherent light generators | 1775 |
| Compositions | 1680 |
| Multiplex communications | 1638 |

development analysis research and practice. Such analysis evaluates performance in technology development based on basic indicators such as the number of issued patents and various citation-based indicators. We summarized relevant indicators for our purpose, and computed these indicators for different types of analytical units.

### *Indicators*

We have adopted key indicators of technology development performance from the literature and industrial practice. Specifically, we used five important indicators from Narin (2000): number of patents, cites per patent, current impact index, technology cycle time, and science linkage, and the technology independence from common industrial practice.

- *Number of patents* indicates company technology development activity.
  Definition: The number of patents issued by the US patent system to an analytical unit (a company, a country or a technology field, etc.).
- *Cites per patent* indicates the impact of an analytical unit's patents.
  Definition: The average number of the citations received by an analytical unit's patents from subsequent patents.
- *Current impact index (CII)* indicates patent portfolio quality.
  Definition: The number of times the analytical unit's patents issued in the most recent 5 years had been cited in the current year, relative to the entire patent database. A value of 1 represents average citation frequency. For the analysis results presented in this report, the current year was set to 2002.
- *Technology independence (TI)* indicates independence of an analytical unit's technology development.
  Definition: The number of self-citations divided by the total number of citations.
- *Technology cycle time (TCT)* indicates speed of invention.
  Definition: The median age in years of the US patent references cited in an analytical unit's patents.
- *Science linkage (SL)* indicates the relationship between an analytical unit's technologies and academic research results.
  Definition: The average number of scientific papers referenced in an analytical unit's patents.

### *Basic analysis results*

The basic analysis results are based on three types of analytical units. We focused on the performance of individual countries and institutions in technology development of the NSE field, as well as the NSE contribution to different technology fields.

*Country analysis*
The total numbers of patents issued to top assignee countries are listed in Table 2. The technologically advanced countries, such as the United States, Japan and France, had controlled the majority of the NSE

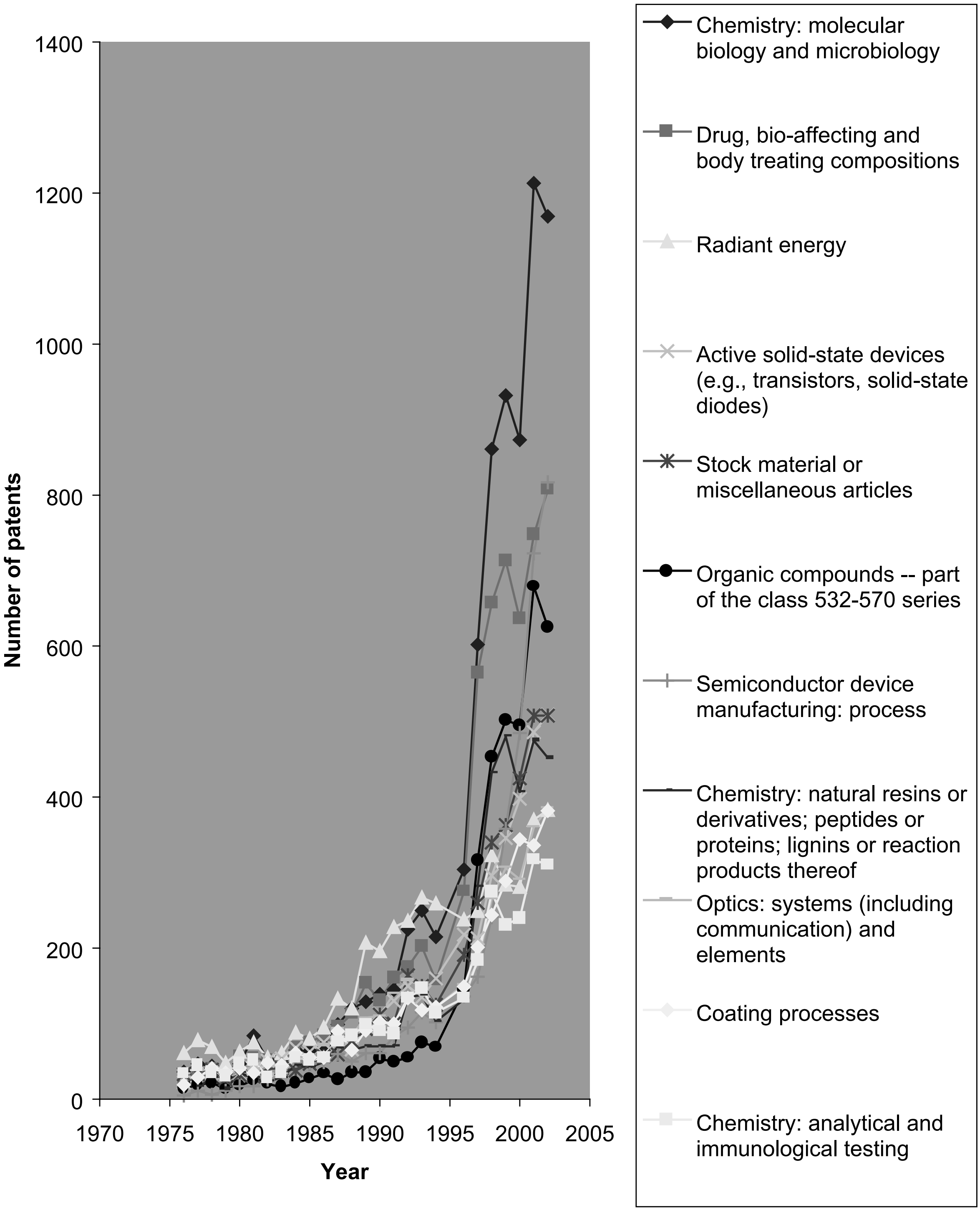


*Figure 4*. Technology field analysis by year (1976–2002).

*Table 11.* Current impact index by technology area (2002)

| Field name | Current impact index |
|---|---|
| Chemistry: molecular biology and microbiology | 3608 |
| Stock material or miscellaneous articles | 1922 |
| Chemistry: analytical and immunological testing | 1917 |
| Radiant energy | 1729 |
| Coating processes | 1697 |
| Drug, bio-affecting and body treating compositions | 1653 |
| Active solid-state devices (e.g., transistors, solid-state diodes) | 1622 |
| Drug, bio-affecting and body treating compositions | 1586 |
| Organic compounds – part of the class 532–570 series | 1474 |
| Semiconductor device manufacturing: process | 1471 |
| Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing | 1446 |
| Optics: systems (including communication) and elements | 1374 |
| Optics: measuring and testing | 1203 |
| Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof | 1063 |
| Radiation imagery chemistry: process, composition, or product thereof | 1027 |
| Chemistry: electrical and wave energy | 987 |
| Static information storage and retrieval | 816 |
| Synthetic resins or natural rubbers – part of the class 520 series | 711 |
| Optical waveguides | 602 |
| Coherent light generators | 536 |
| Compositions | 531 |

patents. The United States was assigned 80% of the US NSE-related patents between 1976 and 2002.

The numbers of patents of the top 14 countries for the years between 1976 and 2002 are shown in Figure 1 and Table 3. From Figure 1, we can observe that the United States, France, Japan, United Kingdom, Switzerland, Netherlands, and Italy begun publishing patents on nanotechnology in the 1970s. Republic of Korea and Taiwan followed later, in the early 1990s. Because the USPTO database only provides full-text access to the patents that are issued after 1976, our data set may have missed some earlier nanotechnology-related patents.

In the analysis on groups of countries, we focused on four groups: the United States (US), Japan (JP), European Commission countries (EC) (including Switzerland), and 'Other' countries (including Korea, Taiwan, China, Canada, Russia, etc.). The government nanotechnology investments for each of these groups of countries (excluding MEMS and other microsystems) are relatively closed in 2003: approximately \$600 for Western Europe, \$750 million for 'others', \$774 for US and \$810 million. The total numbers of nanotechnology-related patents assigned to the four country groups are presented in Table 4. The cites per patent measures indicate that US patents have been cited more frequently by the subsequent patents, followed by Japanese patents and European country patents.

The numbers of patents assigned to the four country groups by year are shown in Figure 2. From this figure we observe that Japan and European countries were at the same level of research and development in the NSE field till 1985. After that year development in Japan began to exceed that in European countries significantly.

*Institution analysis*

The top 20 assignees that have received the greatest number of nanotechnology patents are shown in Table 5. The International Business Machines Corporation (IBM) was issued the greatest number of patents, followed by the Xerox Corporation (Xerox) in the second position. The average patent age measures (as of 2002) reveal differences in the freshness of the patents assigned to these institutions. We can observe that patents issued to the Navy, General Electric, DuPont, and the Dow Chemical Company had an average age of over 10 years, while patents issued to Micron Technology, Lucent Technologies, the Regents of the University of California, Advanced Micro Devices, and NEC were of a much 'younger' age: under 4 years. When considering both quantity and freshness of patents assigned, Micron Technology outperformed all other institutions. It had issued 781 patents (the forth position measured by numbers) with the smallest average patent age (1.9 years), which indicate the company's strong emphasis and potential in this technology area.

The yearly patenting activities of top 10 institutions between 1976 and 2002 are shown in Figure 3 (the institution names are ordered by the total number of patents issued). Assignees in the United States were the early ones getting into the nano-technology field. These assignees including IBM, Xerox, Eastman Kodak, Motorola, Texas Instruments, Minnesota Mining and Manufacturing Company (3M), and the United States of America as represented by the Secretary of the Navy. IBM had maintained its leading position

*Table 12.* Technology cycle time by technology area (1976–2002)

| Field name | Technology cycless time |
|---|---|
| Semiconductor device manufacturing: process | 2 |
| Chemistry: molecular biology and microbiology | 3 |
| Organic compounds – part of the class 532–570 series | 3 |
| Drug, bio-affecting and body treating compositions | 4 |
| Stock material or miscellaneous articles | 4 |
| Drug, bio-affecting and body treating compositions | 4 |
| Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof | 4 |
| Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing | 4 |
| Organic compounds – part of the class 532–570 series | 4 |
| Optical waveguides | 4 |
| Compositions: coating or plastic | 4 |
| Dynamic magnetic information storage or retrieval | 4 |
| Etching a substrate: processes | 4 |
| Active solid-state devices (e.g. transistors, solid-state diodes) | 5 |
| Coating processes | 5 |
| Optics: systems (including communication) and elements | 5 |
| Static information storage and retrieval | 5 |
| Synthetic resins or natural rubbers – part of the class 520 series | 5 |
| Liquid purification or separation | 5 |
| Chemistry: electrical and wave energy | 5 |
| Organic compounds – part of the class 532–570 series | 5 |
| Organic compounds – part of the class 532–570 series | 5 |
| Multiplex communications | 5 |
| Chemistry of inorganic compounds | 5 |
| Synthetic resins or natural rubbers – part of the class 520 series | 5 |
| Plastic and nonmetallic article shaping or treating: processes | 5 |
| Organic compounds – part of the class 532–570 series | 5 |
| Compositions: ceramic | 5 |
| Surgery | 5 |
| Radiation imagery chemistry: process, composition, or product thereof | 6 |
| Chemistry: analytical and immunological testing | 6 |
| Compositions | 6 |
| Electric lamp and discharge devices | 6 |
| Catalyst, solid sorbent, or support therefor: product or process of making | 6 |
| Measuring and testing | 6 |
| Synthetic resins or natural rubbers – part of the class 520 series | 6 |
| Dynamic information storage or retrieval | 6 |
| Electrolysis: processes, compositions used therein, and methods of preparing the compositions | 6 |
| Electricity: electrical systems and devices | 6 |

in most of the years. Micron Technology had shown fast increase in patenting activity in last several years and had risen to the second position, which conformed to the analysis based on total patent number of average patent age discussed previously. Xerox and 3M, although still in the second and third position respectively in terms of the total number of patents issued, had been far behind IBM and Micron in new development of recent years. The patenting activities of Xerox,

*Table 13.* Industry analysis (1976–2002)

| Industry | Number of patents | Cites per patent |
|---|---|---|
| Chemical/catalyst/pharmaceutical | 18784 | 4.22 |
| Electronics | 16704 | 3.53 |
| Materials | 4860 | 4.37 |
| Others | 41352 | 3.73 |

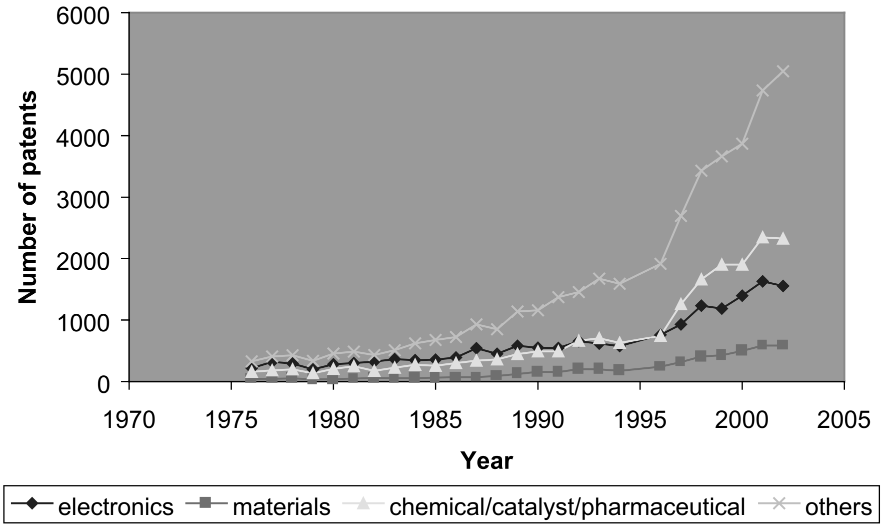


*Figure 5*. Industry analysis by years (1976–2002).

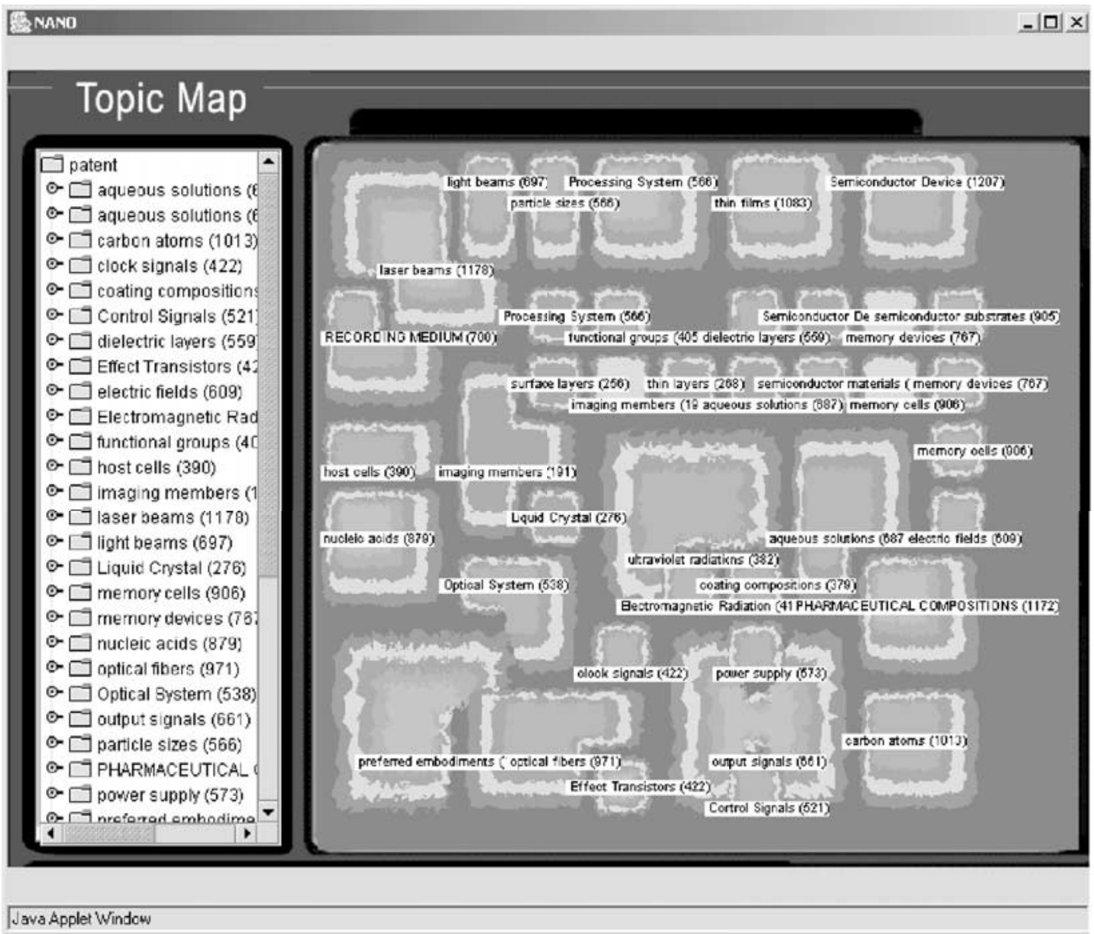


*Figure 6*. First-level technology content map (1976–2002).

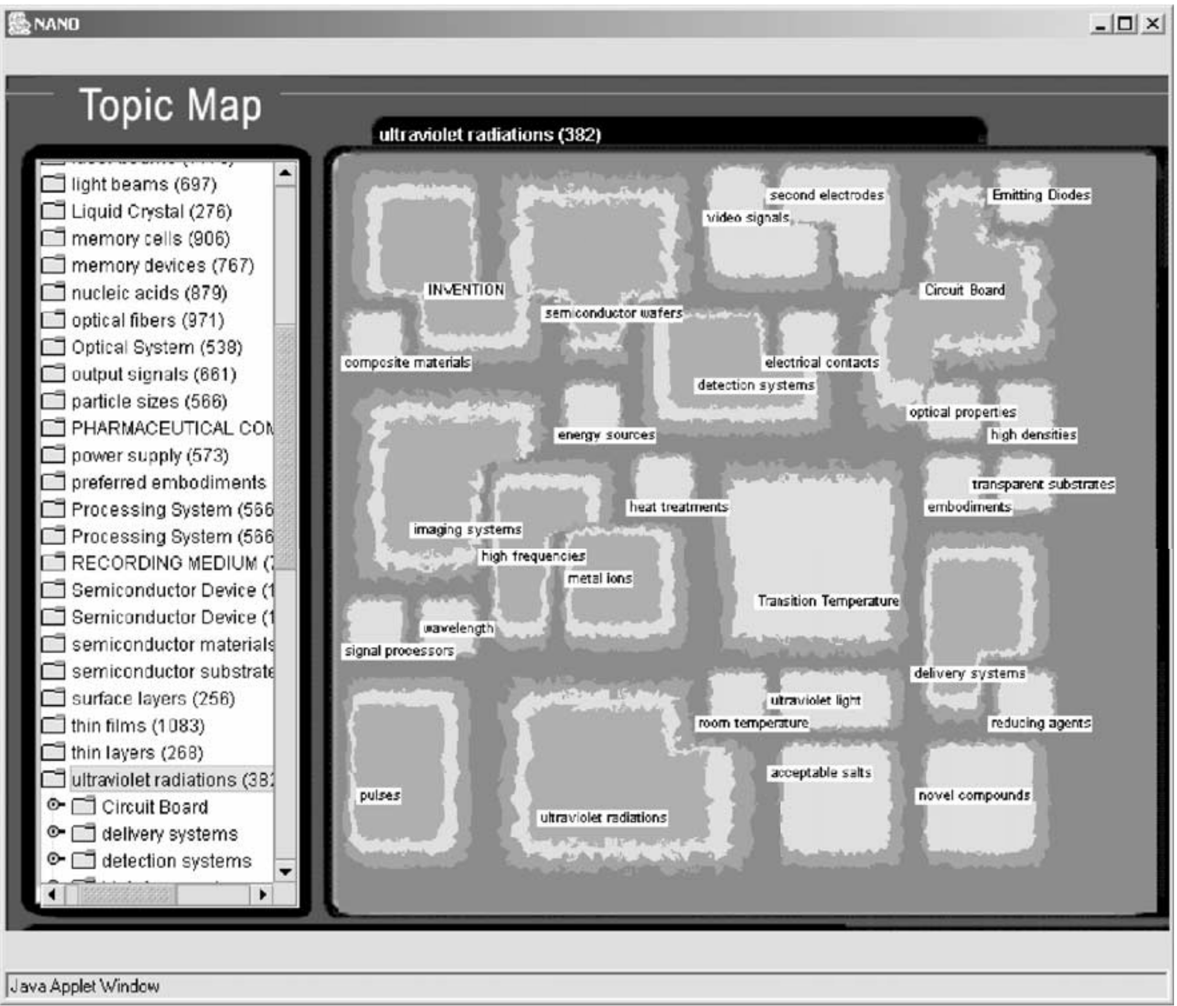


*Figure 7.* Second-level technology concept map: under the region of 'ultraviolet radiations' in the first-level map shown in Figure 6 (1976–2002).

NEC, 3M and the University of California were at the same level in the last several years.

Cites per patent for assignees are shown in Table 6. Patents issued to 3M, the Dow Chemical Company, and California Institute of Technology received the most patent citations: on average each patent of these institutions were cited more than six times by subsequent patents. These institutions might have patents of higher quality than other assignees and might possess key technologies of the field.

The top 10 institutions having the highest technology independence measures are presented in Table 7. These institutions mainly expanded their technology territories by extending from their own patents.

Slow-moving technologies may have longer technology cycle times. It is shown in Table 8 that Advanced Micro Devices, Applied Materials, 3M, and Micron Technology had the shortest cycle times, which indicate that these institutions' patents mostly referenced recent patents and might have represented the cutting edge technologies in the field.

Institutions at the forefront of a technology tend to have stronger science linkage. As shown in Table 9, academic institutions had higher Science Linkage measures (e.g. California Institute of Technology, the University of California, and Massachusetts Institute of Technology). On the other hand, high science linkage measures of companies like Genentech, Micron

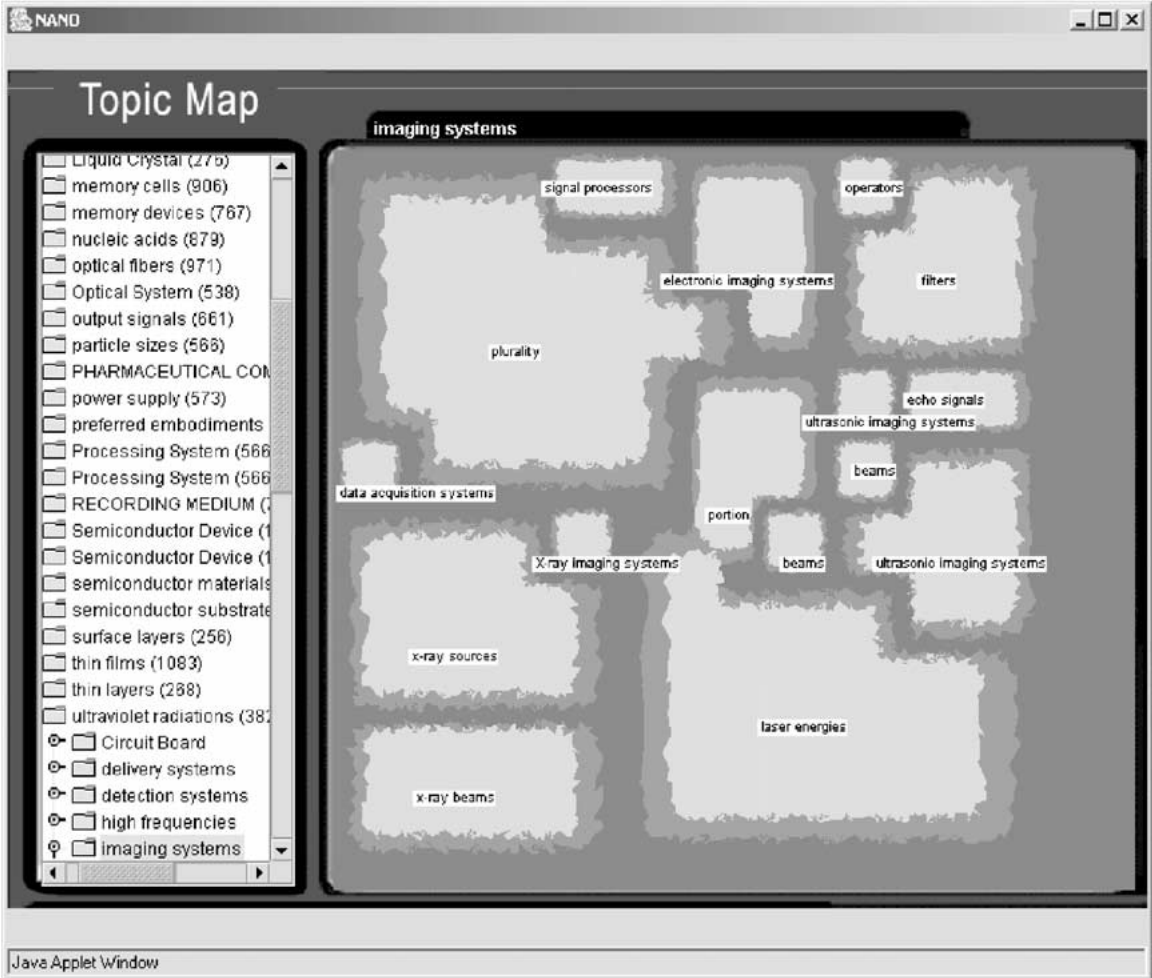


*Figure 8.* Third-level technology concept map: under the region 'imaging systems' in the second-level map shown in Figure 7 (1976–2002).

Technology, Merck and Eli Lilly indicated strong connections between these companies' technology development and academic research.

*Technology field analysis*
Several technology development indicators of top technology fields are presented in this section. The top technology fields to which the NSE-related patents were assigned are presented in Table 10. 'Chemistry: molecular biology and microbiology' and 'drug, bio-affecting and body treating compositions' were revealed to be the dominating technology fields.

Figure 4 reveals trends of the patenting activities in top 10 technology fields between 1976 and 2002. Names of most active technology fields are listed in the figure in order of total number of patents issued. A general observation is that technology fields that experienced fast growth in patenting activity in the recent years include: 'chemistry: molecular biology and microbiology', 'drug, bio-affecting and body treating compositions', 'semiconductor device manufacturing: process', and 'organic compounds – part of the class 532–570 series'.

We also presented technology fields with highest current impact index measures (Table 11) and technology fields with lowest technology cycle time measures (Table 12). 'Chemistry: molecular biology and microbiology' was revealed to be the technology field with the most influential patents, which had been cited frequently by subsequent patents. 'Semiconductor device manufacturing: process', 'chemistry: molecular biology and microbiology', and 'organic compounds – part

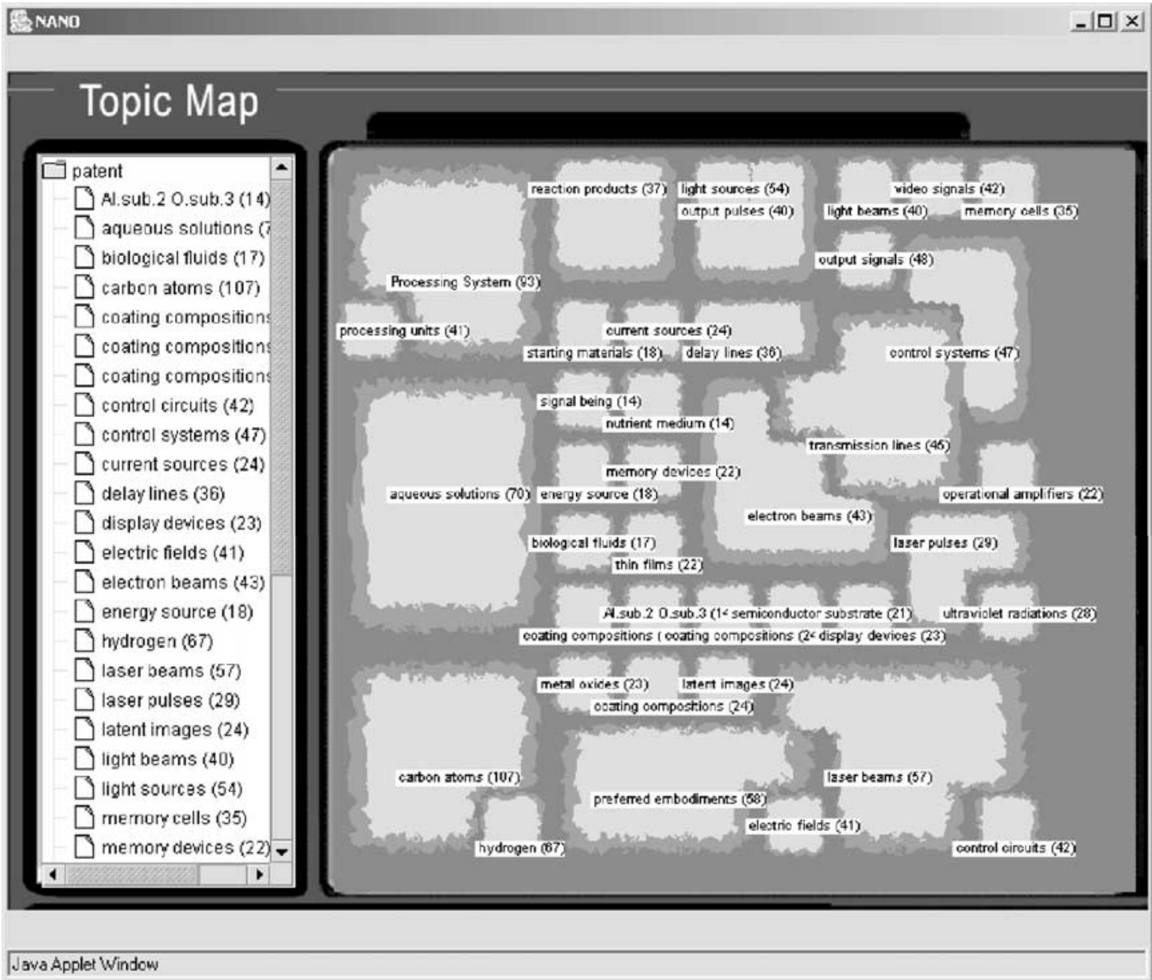


*Figure 9.* Top-layer content map for 1976–1980.

of the class 532–570 series' were revealed to be the technology fields that had been building on the most recent and cutting-edge technology development.

We also compared NSE-related patenting activities in the industry level. In this report we present the comparison among patent development in electronics, materials, chemical/catalysts/pharmaceuticals, and others. We used the US patent classifications to determine the industry of patents. We identified the first-level US classifications that could be categorized into each of the four industries. The total number of patents issued between 1976 and 2002 and the average number of citations received by the patents in these industries are presented in Table 13. The patent development trends of these industries are also presented in Figure 5. We can observe that NSE-related research was dominated by the industries of electronics and chemical/catalysts/pharmaceuticals. Significant growth of patenting activity was also observed in chemical/catalysts/pharmaceuticals industry since 1997.

## Patent content map

Most previous patent analysis research and practice have focused on computing basic and citation-based performance indicators of major players of different levels in the field, as discussed in the last section. It is also valuable to analyze the content of the patents to identify dominating themes and technology topics for researchers to keep update with the most recent

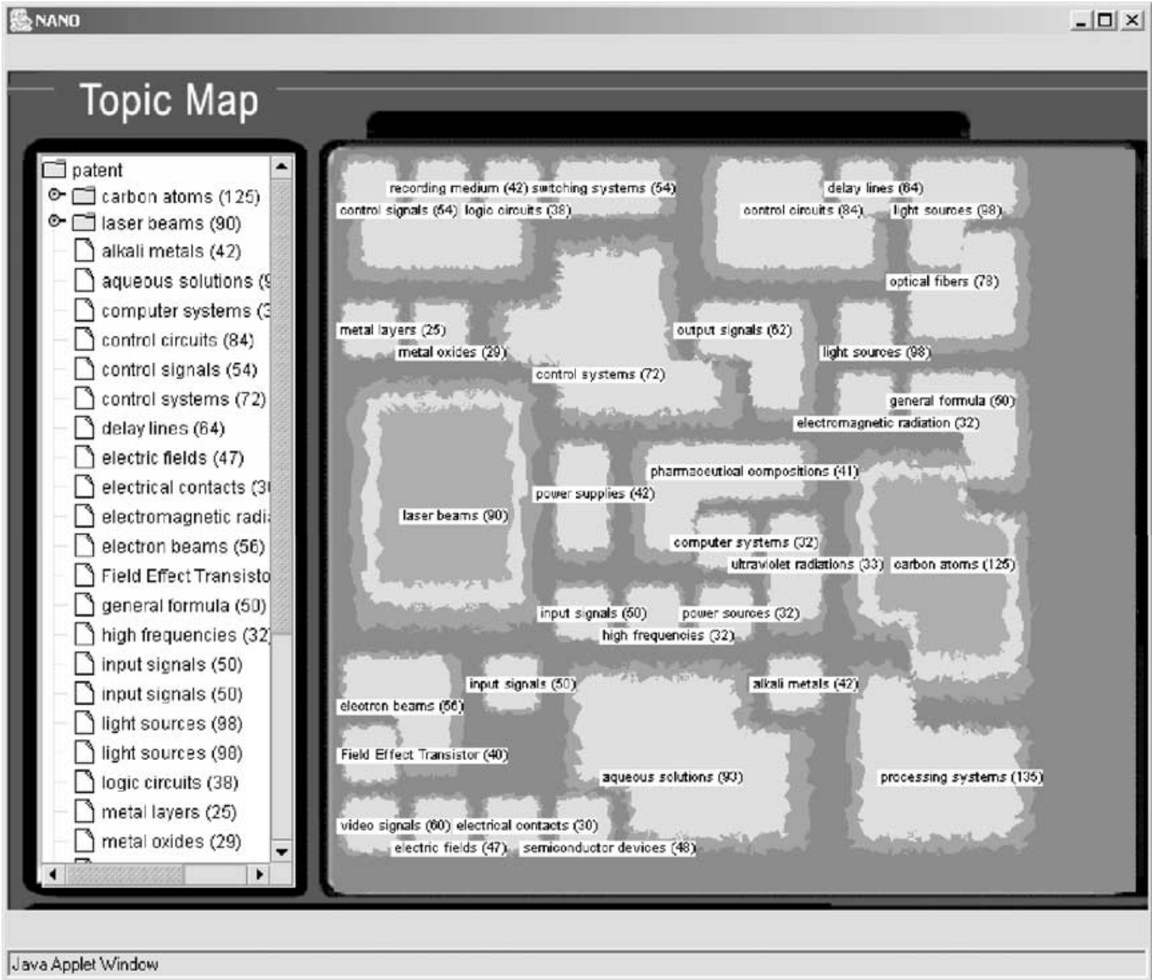


*Figure 10.* Top-layer content map for 1981–1985.

development of the field. We leveraged our previous research in large-scale text analysis and visualization and applied a content map technology to identify and visualize major research topics in the NSE field. Two types of patent content maps are presented below: the overall content map and time-series content maps.

### *Overall content map*

The hierarchical multi-level self-organization map algorithm (Chen et al., 1996; Ong et al., 2003) was used to perform the content analysis of nanotechnology-related patents to discover dominating technology concepts. Figures 6–8 demonstrate three levels of the hierarchical NSE patent content map that was generated based on the titles and abstracts of the 75,852 nanotechnology-related patents in our data set.

The topic map interface contains two components, a folder tree display on the left-hand side and a hierarchical content map in the right-hand side. The patent documents are organized under technology topics that are represented as nodes in the folder tree and colored regions in the content map. These topics were labeled by representative noun phrases that were identified by the heretical self-organizing-map algorithm. Numbers of patent documents that were assigned to the first-level topics are presented in parentheses after the topic labels. Users can either click the fold tree nodes or the content map regions to browse the lower-level topics under a high-level topic. The layers of the colored regions represent the levels of the hierarchies

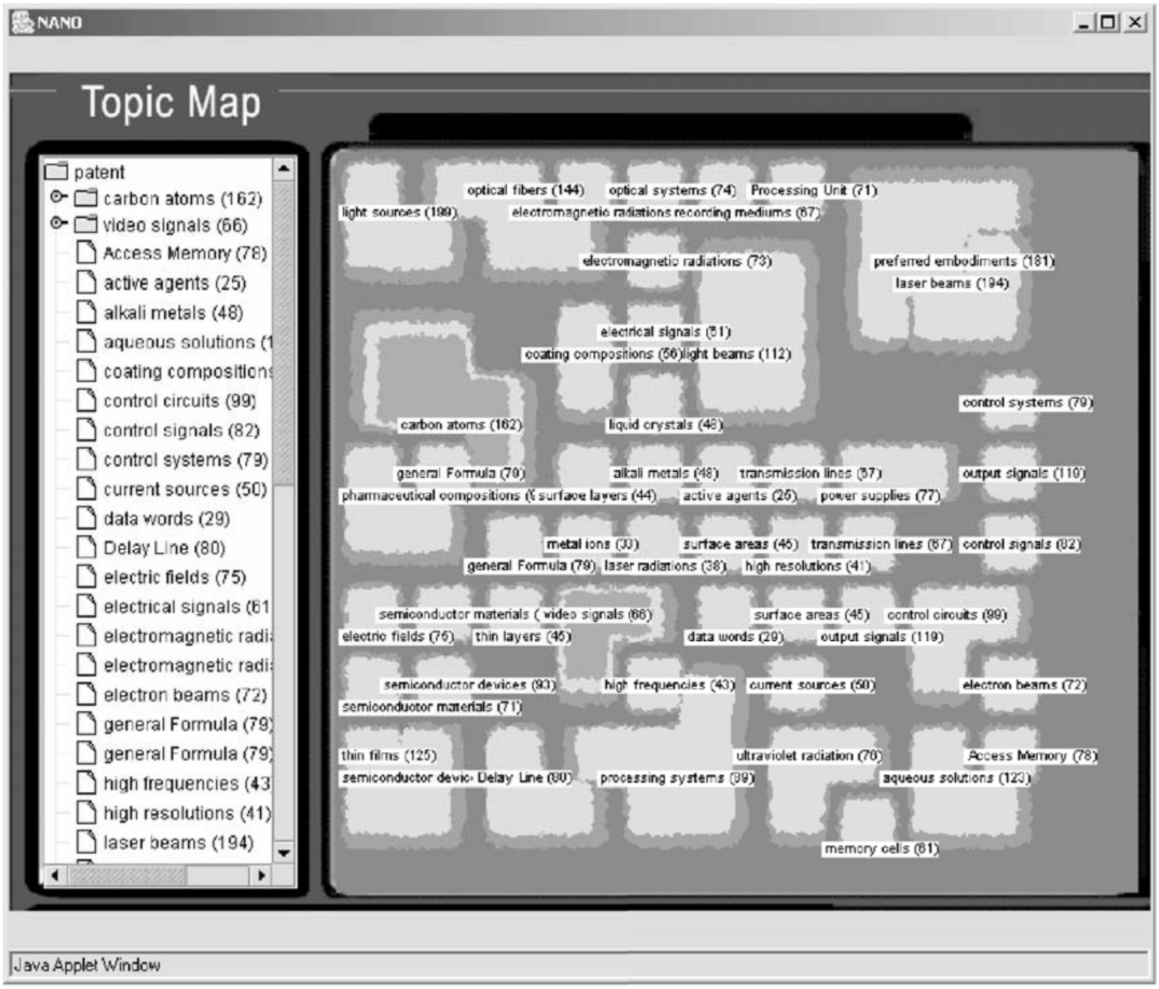


*Figure 11*. Top-layer content map for 1986–1990.

inside the specific regions. The right-hand side content map display shows all topic regions in the same level under a particular higher-level technology topic region.

In each level of such technology maps, conceptually closer technology topics were positioned closer geographically. Conceptual closeness was derived from the co-occurrence patterns of the technology topics in patent titles and abstracts. The sizes of the topic regions also generally corresponded to the number of patent documents assigned to the topics (Lin et al., 2000). First-level technology topics of NSE-related patents are shown in Figure 6. We can observe that closely related technology topics were positioned in neighborhoods (e.g. 'ultraviolet radiations', 'coating compositions', 'electromagnetic radiation', and 'optical systems' in the center of the map).

Technology topics in the lower-level maps were derived from the set of patent documents that belong to a particular higher-level region. As a result, general topics are often found in high-level maps, and more specific technology topics usually appear in low-level maps. The second-level technology topics under 'ultraviolet radiations' are shown in Figure 7. These topics are more specific technology concepts related to 'ultraviolet radiations'. Conceptually closely related topic region neighborhoods can be also observed (e.g. 'heat treatments', 'transition temperature', 'room

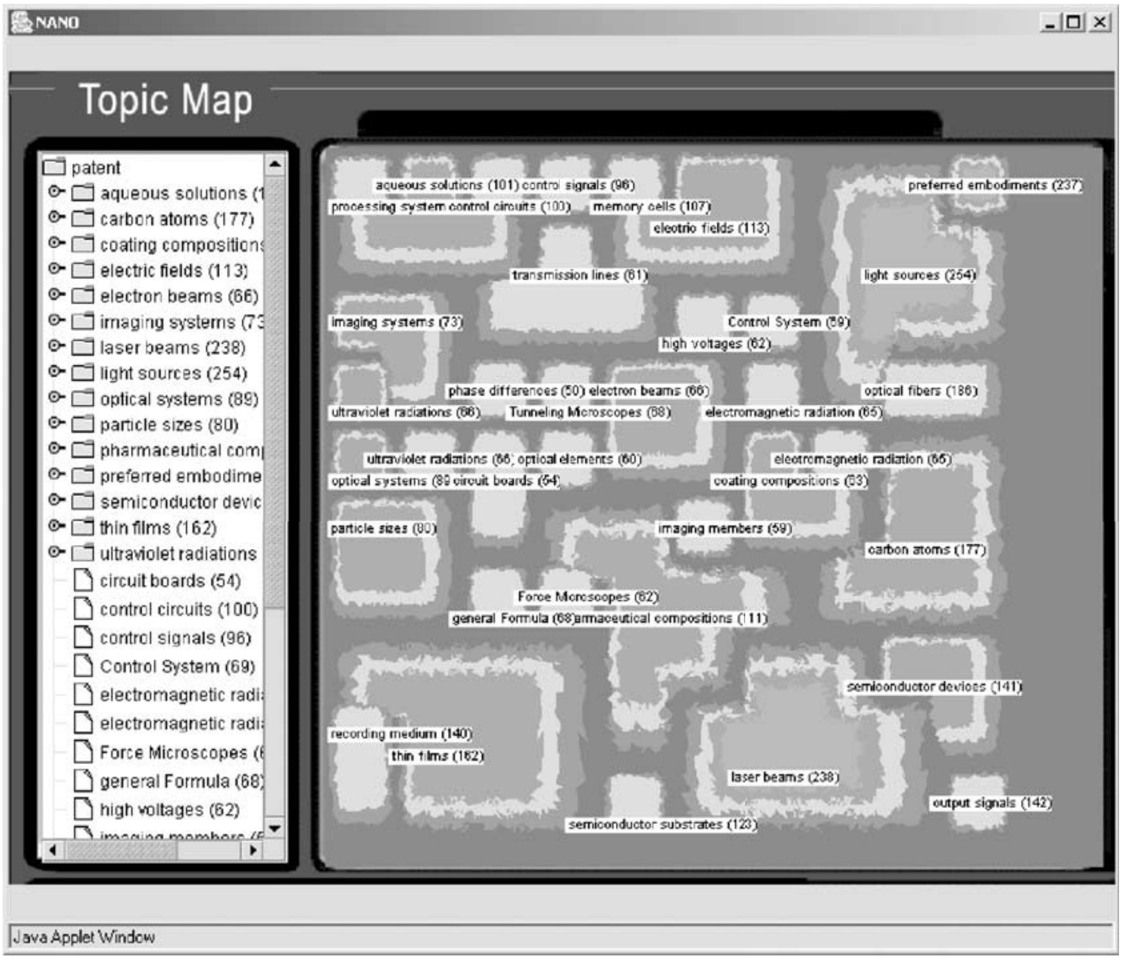


*Figure 12*. Top-layer content map for 1991–1995.

temperature', and 'ultraviolet light' in the center of the map). The third-level technology topic map under 'imaging systems' is presented in Figure 8. The technology topics identified are more specific than the second-level technology topics.

Such a hierarchical technology topic map gives a comprehensive view of the key technology concepts and their relationships in the NSE field. Researchers can visually navigate the NSE landscape with such a tool and identify major areas of interest.

*Time-series content maps*

In order to reveal the evolution of major technology topics in the NSE field, we generated content maps for several time periods. Specifically, we created six content maps for the time periods of:

- 1976–1980 (3244 patents), map represented in Figure 9,
- 1981–1985 (4601 patents), Figure 10,
- 1986–1990 (8153 patents), Figure 11,
- 1991–1995 (10447 patents), Figure 12,
- 1996–2000 (27891 patents), Figure 13,
- 2001–2002 (15524 patents), Figure 14.

By comparing the dominating regions in the top-level content maps in different time periods, we can observe some general trends in nanotechnology development.

It can be observed that dominating topic regions between 1976 and 1980 are: 'processing systems', 'aqueous solutions', 'transmission lines', 'electron

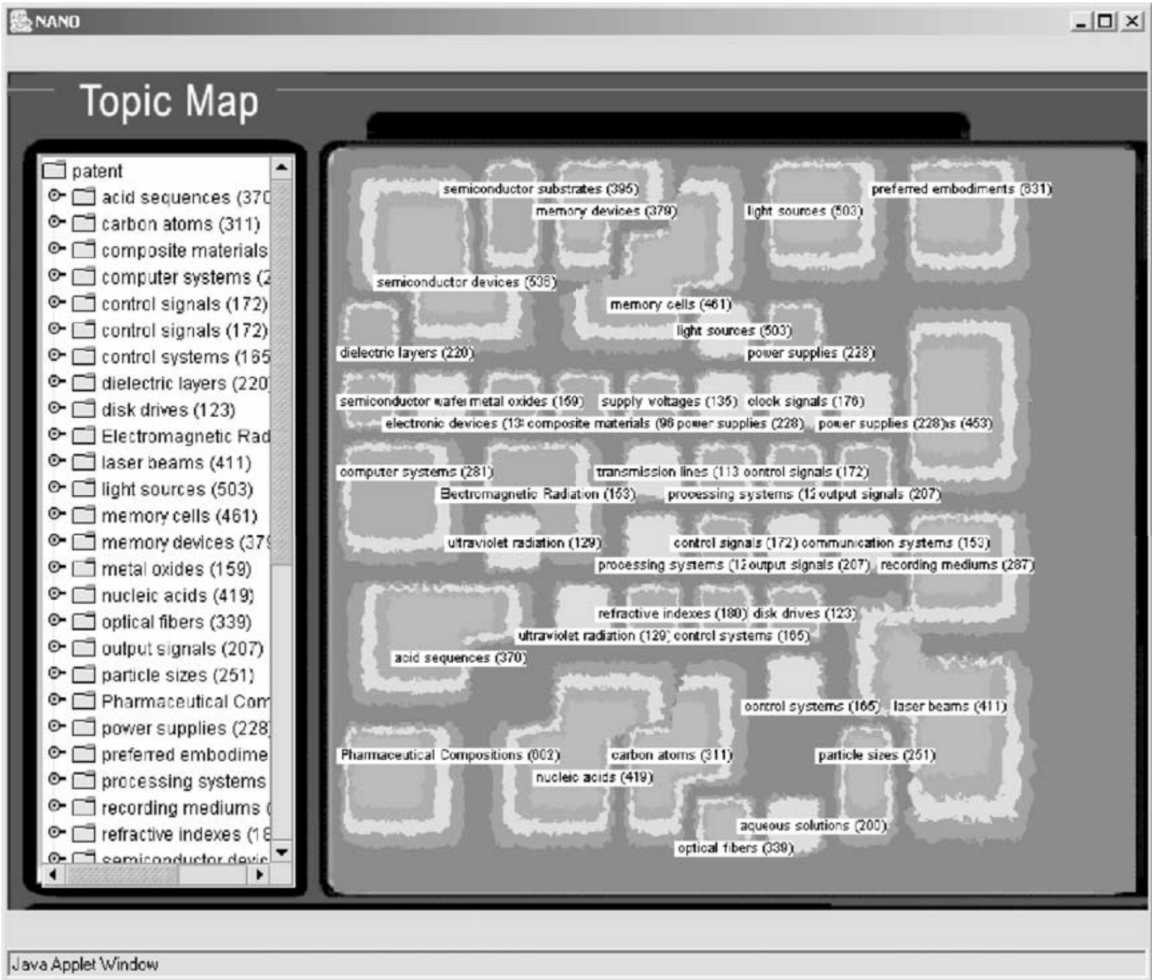


*Figure 13*. Top-layer content map for 1996–2000.

beams', 'carbon atoms', preferred embodiments', and 'laser beams'. The sizes of these topic regions suggest that they were the key technology topics during the early years of NSE technology innovation.

During 1981–1985, dominating topics in the previous 5 years, such as 'laser beams', 'carbon atoms', 'aqueous solutions', and 'processing systems', continued to be important technology topics. At the same time, new topics like 'control signals', 'control circuits', 'control systems', and 'pharmaceutical compositions' also began to occupy dominating positions.

During 1986–1990, active technology topics during the previous 5 years continued to be the central areas of interest for patenting activities. 'Preferred embodiments' also returned to the main scene. Three new important topics are observed: 'light beams', 'video signals', and 'semiconductor devices'.

During 1991–1995, the most important technology topics were 'light sources', 'carbon atoms', 'pharmaceutical compositions', 'thin films', and 'laser beams'. 'Light sources' and 'thin film' had experienced a remarkable growth and had become equally important as the other three topics that had long-term dominance in the field. Other important new topics include: 'imaging systems', 'tunneling microscopes', 'coating compositions', and 'particle sizes'.

During 1996–2000, 'semiconductor devices' regained the dominating position. New topics like 'memory cells', 'computer systems', 'electromagnetic radiation', 'acid sequences', and 'nucleic acids' began to become major technology topics in the NSE field.

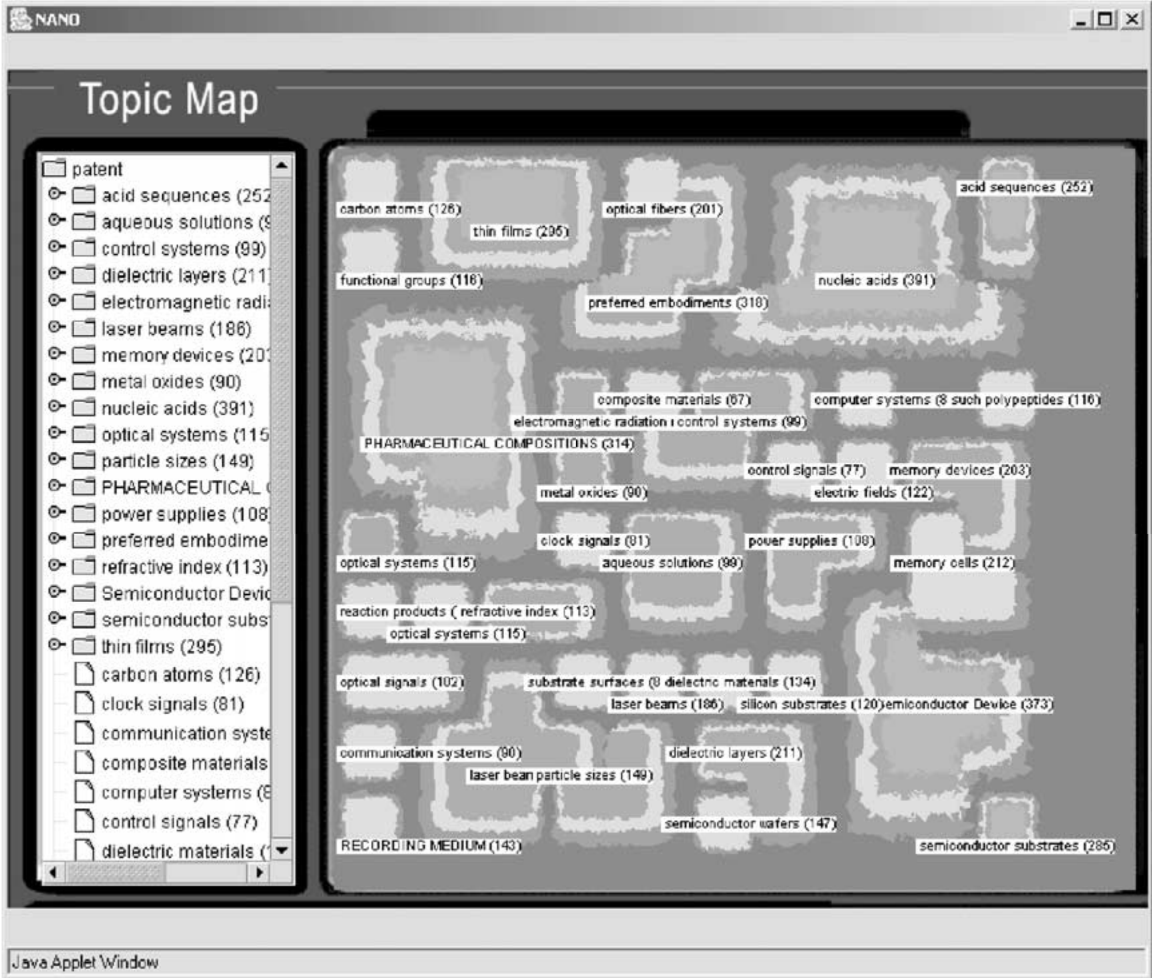


*Figure 14.* Top-layer content map for 2001–2002.

Major technology topics of the patents issued in the last 2 years (2001 and 2002) are shown in Figure 14. We have not observed important new topics that occupied the dominating positions. The most important topics continued to be 'nucleic acids', 'pharmaceutical compositions', 'laser beams', and 'semiconductor devices.' Several new topics can be observed but with smaller region sizes, including 'optical systems', 'refractive index', 'optical signals', 'power supplies', and 'dielectric layers.' These topics represent the most recent technology topics in the field and indicate potential future development trends.

The overall and time-series NSE technology content maps presented in this section were generated based on the entire NSE-related patent collection. The

*Table 14.* Country codes and names

| Country code | Country name | Country code | Country name |
|---|---|---|---|
| AN | Netherlands Antilles | GB2 | England |
| AT | Austria | IT | Italy |
| AU | Australia | JP | Japan |
| BE | Belgium | KR | Republic of Korea |
| CH | Switzerland | NL | the Netherlands |
| DK | Denmark | NO | Norway |
| DT | Germany | SE | Sweden |
| FI | Finland | SG | Singapore |
| FR | France | TW | China (Taiwan) |
| GB | United Kingdom | US | United States |

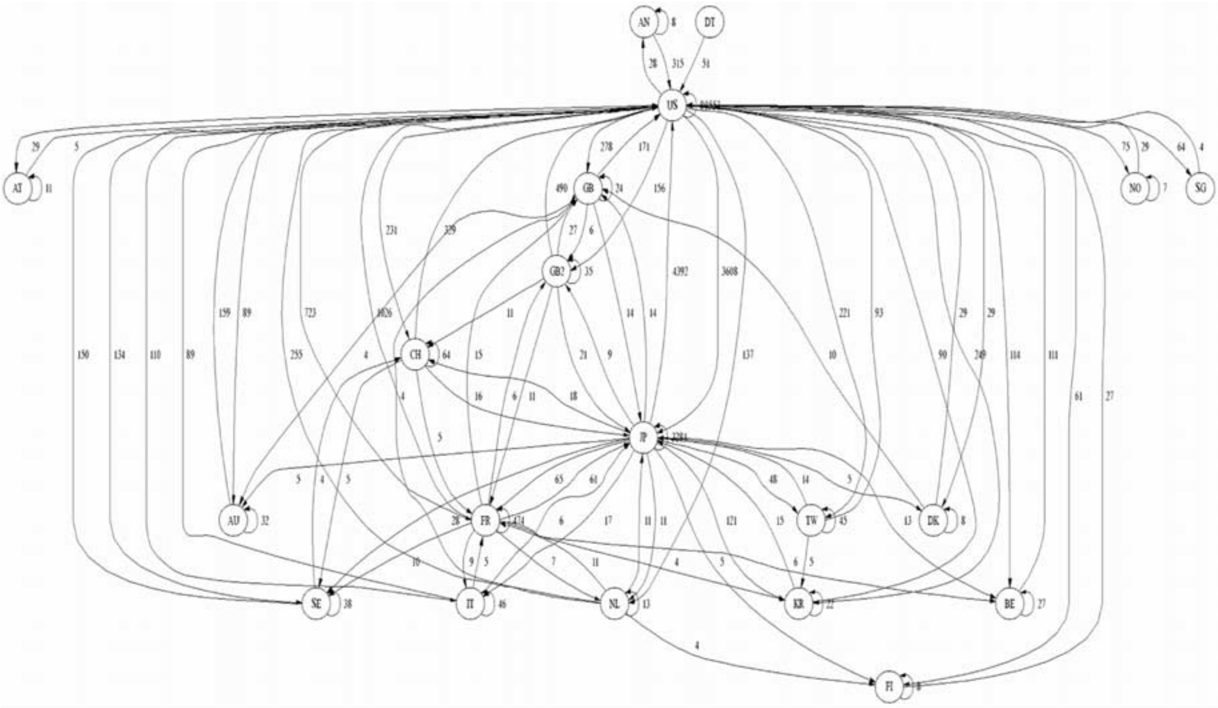


*Figure 15.* Country citation network (minimum cites: 3) (1976–2002).

technology is also applicable to analyze and visualize NSE technology landscapes of individual analytical units when applied to a specified sub set of NSE patent documents (e.g. NSE content maps of individual countries, institutions and technology fields).

## Citation network

A large amount of valuable information is embedded in patent citations. We computed and summarized the citation information for different analytical units: countries, institutions and technology fields. Based on such citation information, we applied existing network drawing algorithms to generate a visual network of patent citations. Such a network can be used to visually present the transfer of knowledge among different analytical units.

The citation networks presented in this section are derived from the entire set of patents in the data set, which covers nanotechnology-related patents from 1976 to 2002. In these networks, arrow direction of the links represents the direction of the citation. For example, a link with the form, 'Country A → Country B' means that country A's patents had been cited by cited country B's patents, and the number besides the link represents the total number of these citations.

The networks presented in this section are generated by an open source graph drawing software, Graphviz, provided by AT&T Research... (Gansner & North, 2000) (available at: http://www.research.att.com/sw/tools/graphviz/).

### *Country citation network*

The nanotechnology-related patent citation networks among countries are presented in this section. The codes and names of top 20 countries are shown in Table 14 (country codes were from USPTO: http://www.uspto.gov/patft/help/helpctry.htm).

The most complete citation network among countries is presented in Figure 15. A citation link between two countries is presented in the map if there are more than three patent citations associated with the link.

Figures 16 and 17 present citation networks in which the citation links with small number of citations were

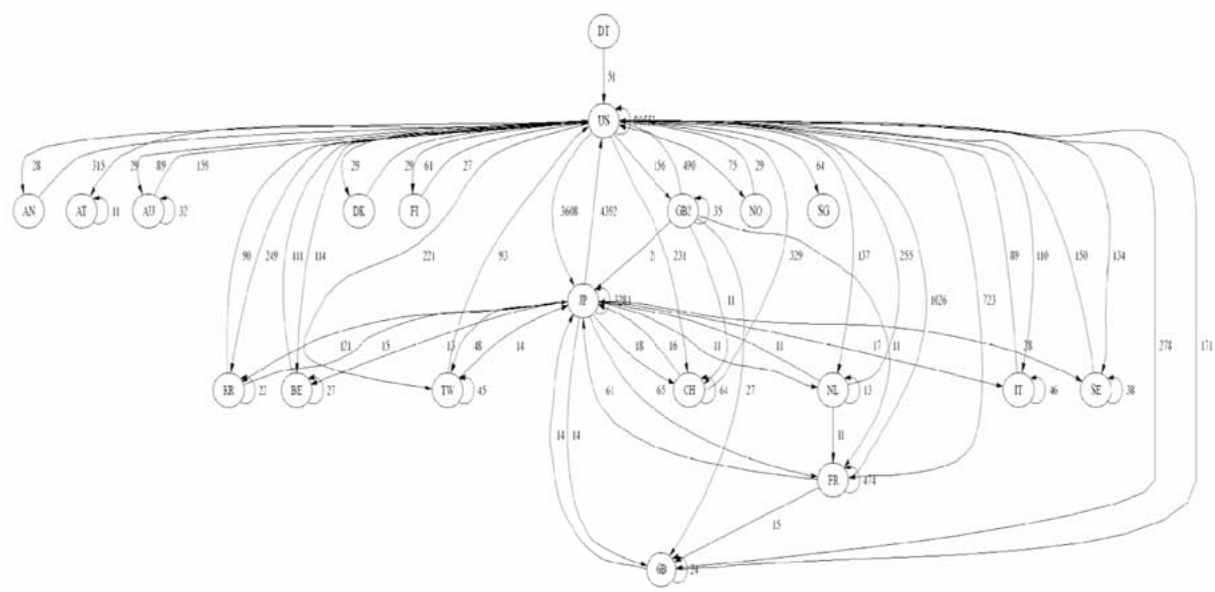


*Figure 16*. Country citation network (minimum cites: 10) (1976–2002).

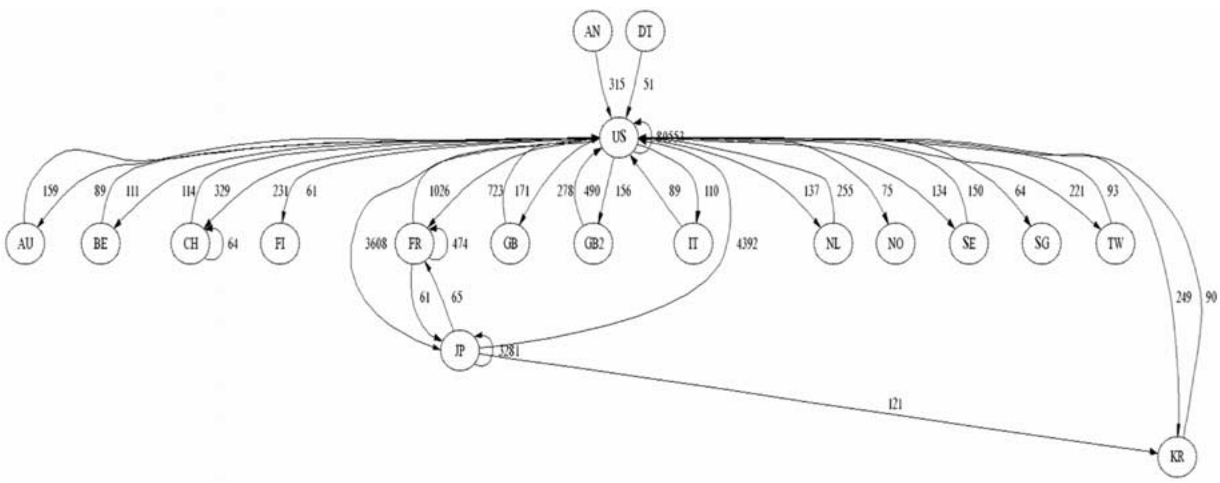


*Figure 17*. Country citation network (minimum cites: 50) (1976–2002).

filtered. Figure 16 presents a network with links having at least 10 citations, and Figure 17 presents a network with links having at least 30 citations.

The general observations from these citation networks are (mainly based on Figure 15):

- the United States (US) dominated most of the citations and the US patents intensively interacted with patents of most other countries;
- Japan (JP) was the second largest patent citation center following the United States;
- other patent citation centers included France (FR), Great Britain (GB and GB2), and Switzerland (CH). There were large amounts of citation activities among the patents of the United States and these countries;
- patents of Austria (AT), Netherlands Antilles (AN), Germany (DT), Norway (NO) and Singapore (SG) only interacted with the patents

of the United States, but not other citation centers;

- several local country citation networks can be observed. Groups of the countries that had formed such local networks are: (1) United Kingdom (GB) and England (GB2); (2) France, Sweden (SE), Italy (IT), and Netherlands (NL); and (3) China (Taiwan) (TW) and Korea (KR).

*Institution citation network*

The top 50 institutions that own the greatest number of patents in the nanotechnology field are presented in Table 15. We assigned institution ids for analysis and display purposes.

Similarly to the country citation networks, three levels of citation networks are presented in Figures 18–20. The minimum number of citations specified for the citation links in Figures 18–20 are 5, 10 and 50, respectively.

Some general observations are (mainly based on Figure 20):

- IBM (24145) and Micron Technology, Inc. (36501) were the institutional patent citation centers. Patents of these two companies were cited intensively by patents of other institutions.
- Patents of Kabushiki Kaisha Toshiba (24661), Massachusetts Institute of Technology (25905), Matsushita Electric Industrial Co., Ltd. (25959), Hitachi, Ltd. (23330), Digital Equipment Corporation (19486), and Hewlett-Packard Company (23244) mainly interacted with patents of IBM.
- Patents of RCA Corporation (29312), National Semiconductor Corporation (27204), 3M (26602) mainly interacted with patents of Micron Technology.
- Patents of Taxes Instruments Inc. (31877), Advanced Micro Devices, Inc. (17089), Motorola, Inc. (26909), and Intel Corporation (24073) interacted with patents of both IBM and Micron Technology.
- There had been several other local patent citation networks. Groups of institutions that had formed such networks are: (1) 3M (26602 and 16845), the Dow Chemical Company (32084), and US Philips Corporation (33125); (2) Digital Equipment Corporation, Xerox Corporation (34210), and Eastman Kodak Company (21312); and (3) Bayer Aktiengesellschaft (18158) and Lucent Technologies Inc. (25610).

*Table 15.* Top 50 Institutions – ids and names (1976–2002)

| Institution Id | Institution name |
|---|---|
| 16845 | 3M Innovative Properties Company |
| 16922 | Abbott Laboratories |
| 17089 | Advanced Micro Devices, Inc. |
| 17903 | AT&T Bell Laboratories |
| 18158 | Bayer Aktiengesellschaft |
| 18537 | Bell Telephone Laboratories, Incorporated |
| 18641 | California Institute of Technology |
| 19393 | Canon Kabushiki Kaisha |
| 19486 | Digital Equipment Corporation |
| 21088 | Dow Corning Corporation |
| 21271 | E. I. Du Pont de Nemours and Company |
| 21312 | Eastman Kodak Company |
| 21545 | Eli Lilly and Company |
| 22326 | Fuji Photo Film Co., Ltd. |
| 22357 | Fujitsu Limited |
| 22539 | Genentech, Inc. |
| 22605 | General Electric Company |
| 23244 | Hewlett-Packard Company |
| 23330 | Hitachi, Ltd. |
| 23417 | Honeywell Information Systems Inc. |
| 23489 | Hughes Aircraft Company |
| 24073 | Intel Corporation |
| 24145 | IBM |
| 24661 | Kabushiki Kaisha Toshiba |
| 25085 | L'Oreal |
| 25586 | LSI Logic Corporation |
| 25610 | Lucent Technologies Inc. |
| 25905 | Massachusetts Institute of Technology |
| 25959 | Matsushita Electric Industrial Co., Ltd. |
| 26268 | Merck & Co., Inc. |
| 26501 | Micron Technology, Inc. |
| 26602 | 3M |
| 26650 | Mitsubishi Denki Kabushiki Kaisha |
| 26909 | Motorola, Inc. |
| 27204 | National Semiconductor Corporation |
| 27245 | NEC Corporation |
| 28859 | PPG Industries, Inc. |
| 29312 | RCA Corporation |
| 29701 | Rohm and Haas Company |
| 30666 | SmithKline Beecham Corporation |
| 30873 | Sony Corporation |
| 31877 | Texas Instruments Incorporated |
| 32084 | The Dow Chemical Company |
| 32311 | The Regents of the University of California |
| 32505 | The United States of America as Represented by the Secretary of the Air |
| 32508 | The United States of America as represented by the Secretary of the Army |
| 32512 | The United States of America as represented by the Secretary of the Navy |
| 32524 | The United States of America as represented by the United States |
| 33125 | US Philips Corporation |
| 34210 | Xerox Corporation |

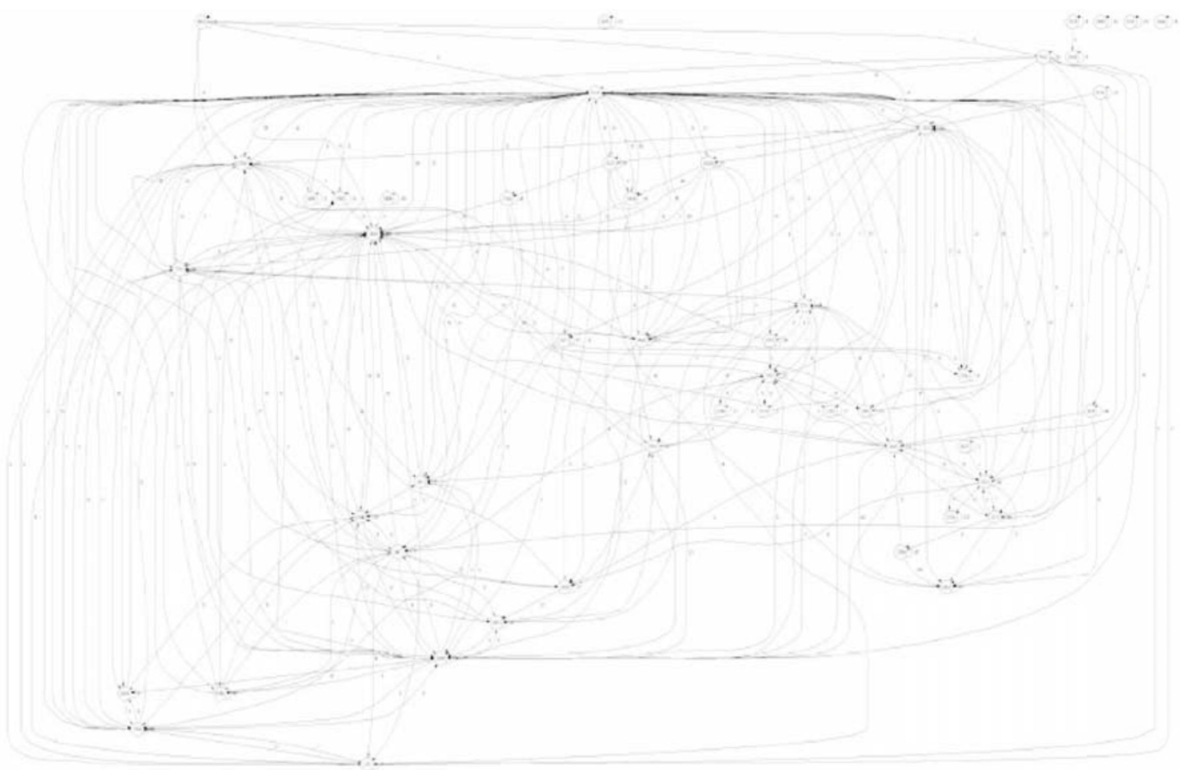

*Figure 18.* Institution citation network (minimum cites: 5) (1976–2002).

*Technology field citation network*

The top 50 technology fields that had the greatest number of patents are presented in Table 16.

These technology fields were derived from the first-level US Patent Classification categories (available at: http://www.uspto.gov/go/classification/selectnumwithtitle.htm. Some categories have identical names, however, the detailed specification of such categories are different). In future analysis, such categories can be grouped together to form higher-level technology fields.

Three versions of the technology field citation networks are presented in Figures 21–23. The minimum numbers of citations in these networks are 200, 300 and 800, respectively. Such citation networks have the potential to reveal underlying connections among the technology fields.

General observations from these networks are (mainly based on Figure 23):

- The fields of 'chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof' (530) and 'chemistry: molecular biology and microbiology' (435) were the dominating patent citation centers. The patents of these two fields interacted intensively with patents in other fields that were in the major technology field citation network.
- Patents of 'drug, bio-affecting and body treating compositions' (514), 'drug, bio-affecting and body treating compositions' (424), 'chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof' (530) and 'chemistry: molecular biology and microbiology' (435) had formed an interconnected citation network.
- The patents of 'chemistry: analytical and immunological testing' (436) and 'organic compounds – part of the class 532–570 series' (536), and 'chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof' (530) and 'chemistry: molecular biology and microbiology' (435) had formed an interconnected citation network.
- Patents of 'chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing'

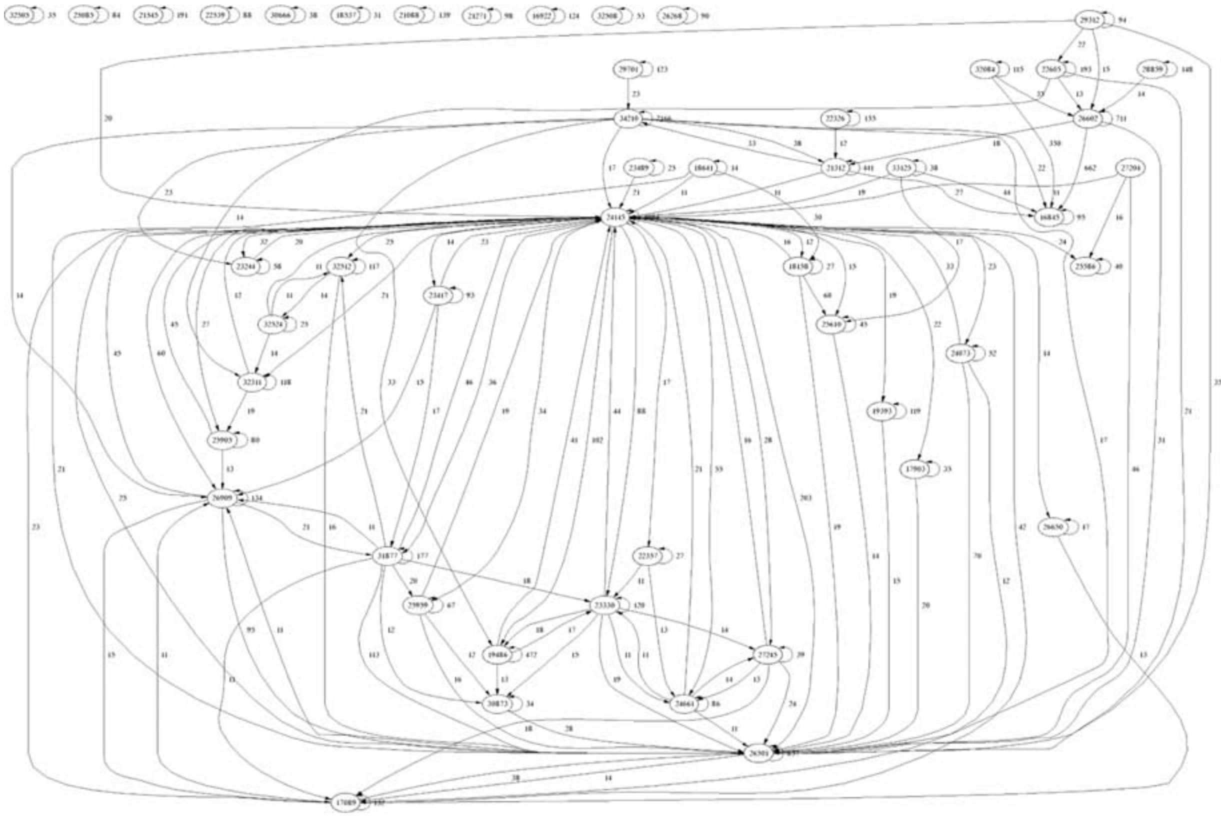

*Figure 19.* Institution citation network (minimum cites: 10) (1976–2002).

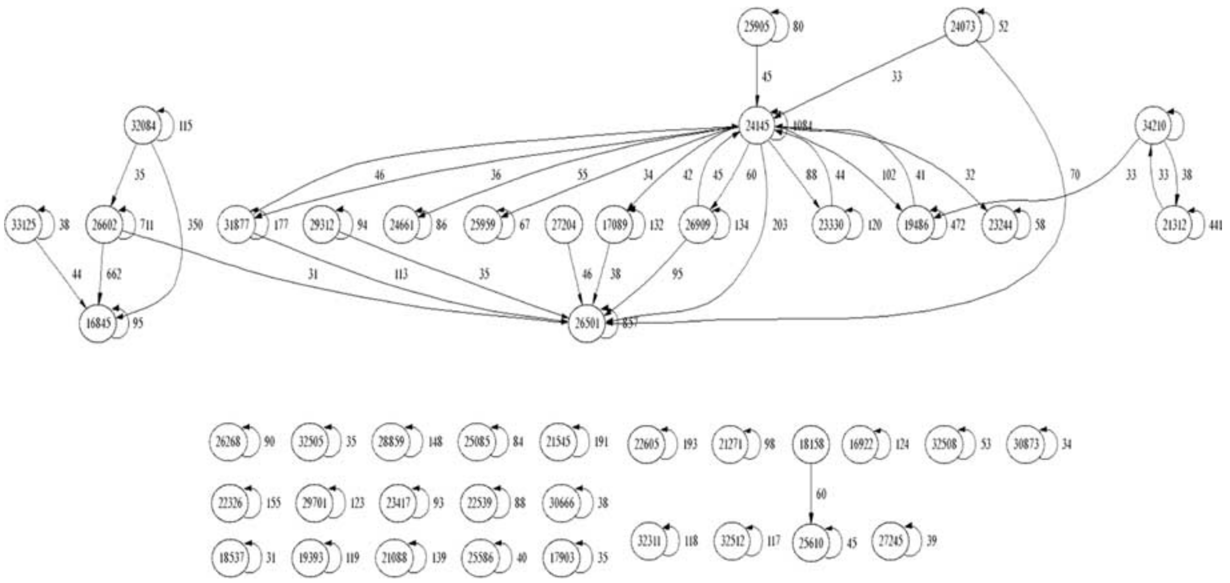


*Figure 20.* Institution citation network (minimum cites: 30) (1976–2002).

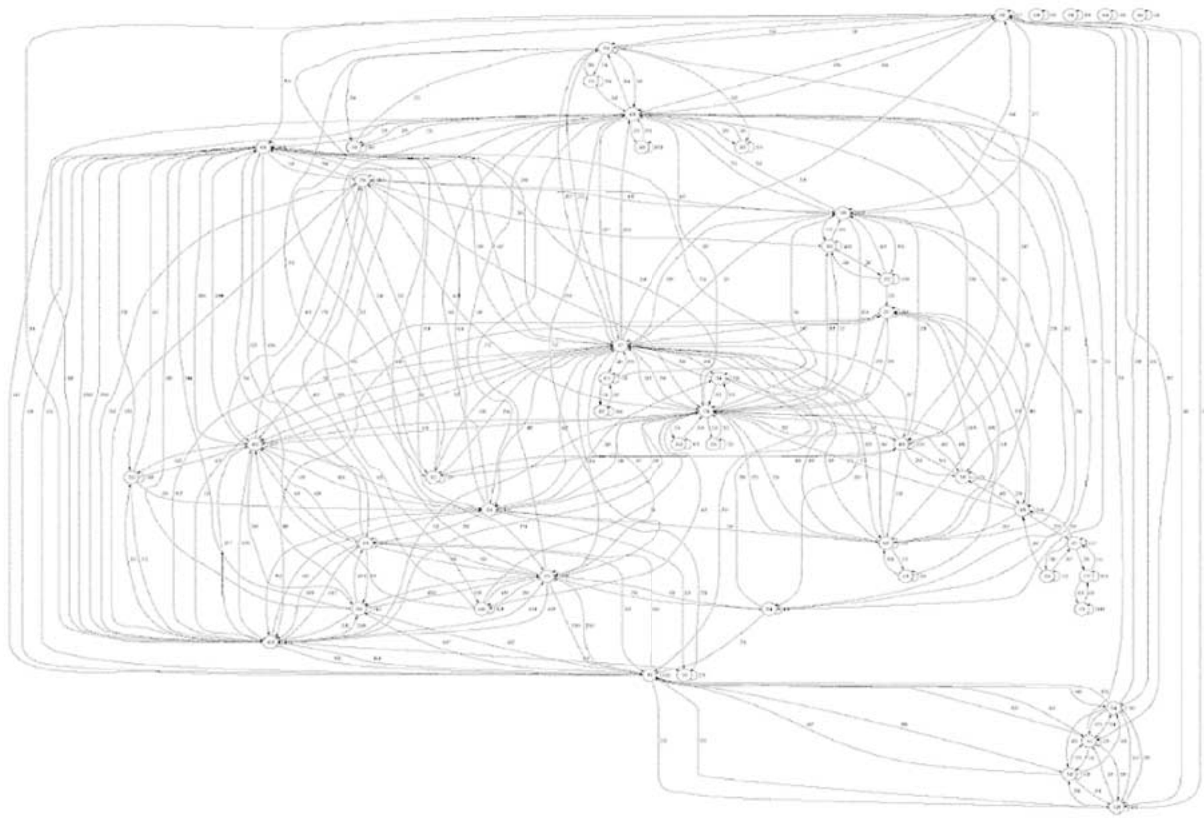

*Figure 21*. Technology field citation network (minimum cites: 200) (1976–2002).

(422) had interacted intensively with the patents of 'chemistry: molecular biology and microbiology' (435) and 'chemistry: analytical and immunological testing' (436).

- Patents of 'chemistry: electrical and wave energy' (204) had been cited by patents of 'chemistry: molecular biology and microbiology' (435) and 'chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing' (433) intensively.
- Patents of 'organic compounds – part of the class 532–570 series' (544 and 546) had been cited by patents of 'drug, bio-affecting and body treating compositions' (514) intensively.
- There had been several local technology field citation networks. Groups of technology fields that had formed such networks are: (1) 'active solid-state devices (e.g. transistors, solid-state diodes)' (257) and 'semiconductor device manufacturing: process' (438); (2) 'coating process' (427) and 'stock material or miscellaneous articles' (428); and (3) 'radiant energy' (250) and 'optics: measuring and testing' (356).

## Conclusion and future directions

Several analysis and visualization techniques on NSE-related US patent documents have been applied for the interval 1976–2002 with the data available by April 2003. Three investigations, including basic analysis, content map analysis and citation network analysis, were conducted on individual countries, institutions and technology fields. Based on observations of the analysis results, certain levels of knowledge regarding technology performances transfer of knowledge and development trends have been captured.

The UPTO offers a representative database because of the simultaneous submission of claims in the United States (as the largest commercial market) and

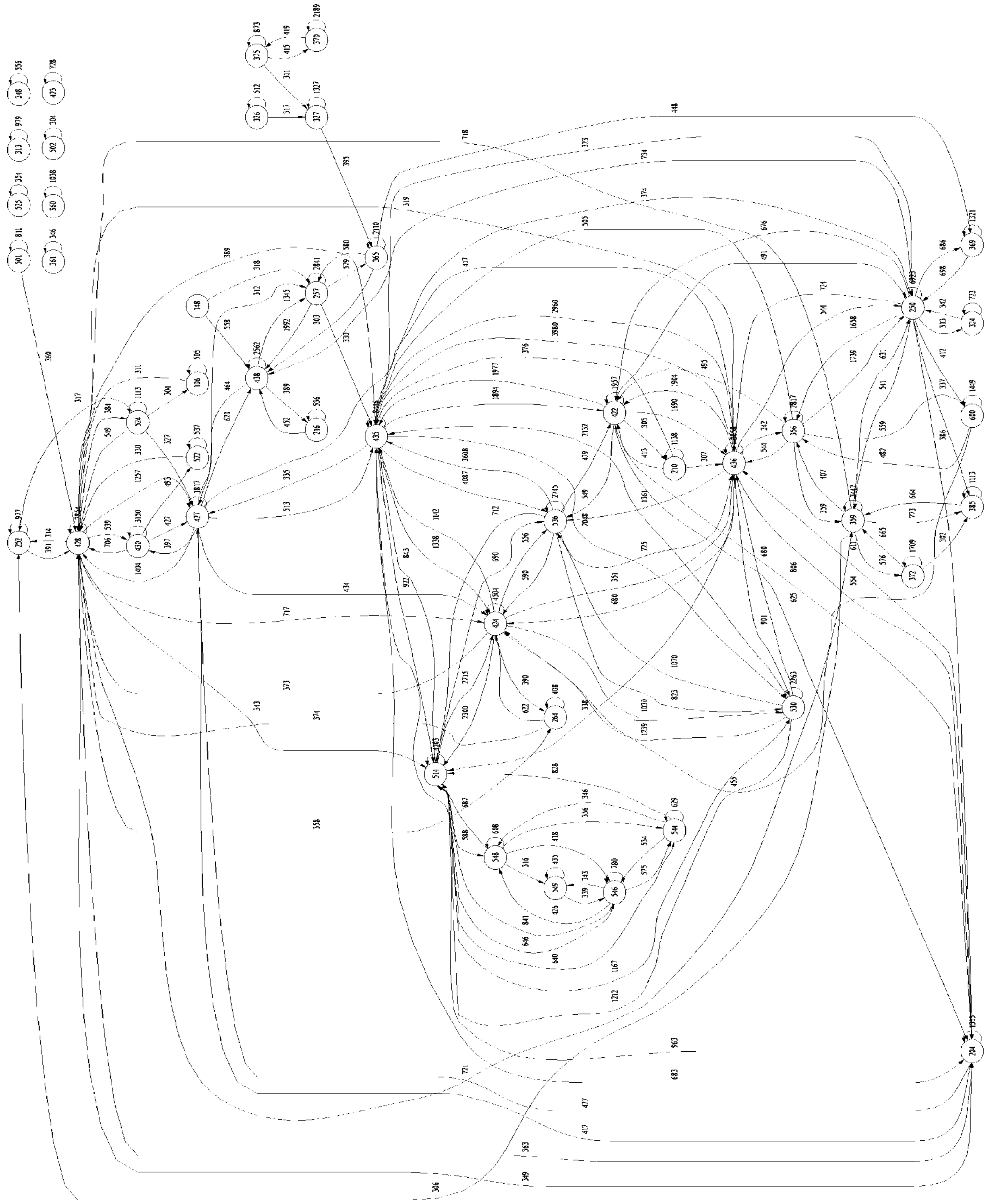

*Figure 22.* Technology field citation network (minimum cites: 300) (1976–2002).

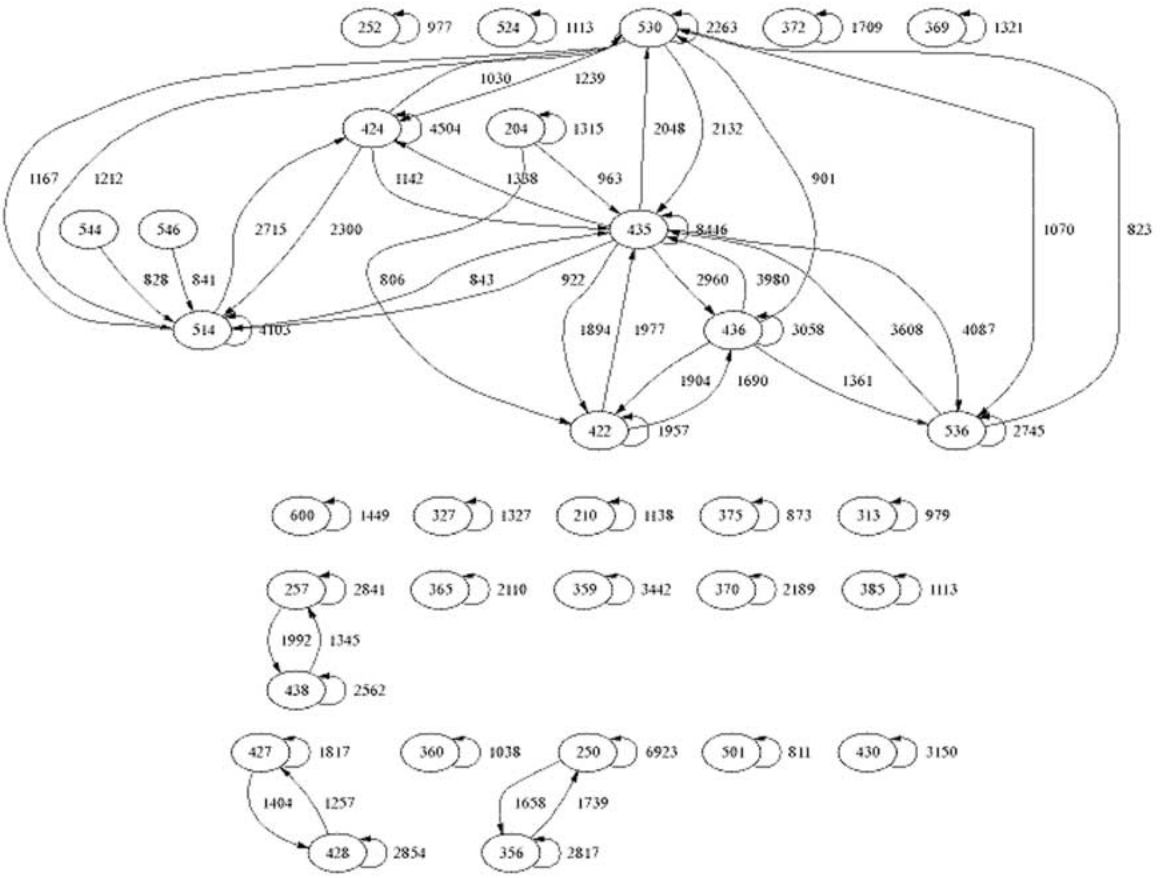


*Figure 23*. Technology field citation network (minimum cites: 800) (1976–2002).

abroad. In the last two decades, the rate of increase of nanotechnology patents is exponential as a function country and topic. Of 22,608 patents on nanotechnology awarded since the announcement of NNI (in the interval January 2000 to April 2003), 79.0% were assigned to US inventors, 12.4% to Japan, 3% to France, 1.1% to UK, 1% to Taiwan, 0.9% to each Korea and Netherlands, 0.7% to Switzerland, 0.5% to each Italy and Australia. The fastest growth in the patenting activity in the last 5 years has been in chemical and pharmaceutical fields, followed by semiconductor devices. The leading technology topics have significantly changed in the last decades. In 2001–2002, the most important topics were 'nucleic acids', 'pharmaceutical composition', 'laser beams', 'semiconductor devices' and 'optical systems'.

The paper represents the first step toward a generic framework of patent analysis for scientific domains. Other potential applications include natural language processing, social network analysis, data mining and other visualization techniques to perform the three types of analysis: performance evaluation, transfer of knowledge analysis and technology trend analysis. We plan to expand the approach to provide Web-based patent analysis services and other services such as patent recommendation, patent competitive analysis, etc. Another important future direction is the systematic evaluation of the usefulness and reliability of knowledge discovery and visualization results. The evaluation will include two aspects: whether the patent-based information (performance indicators, content, citations) reflects underlying technology

*Table 16.* Technology field names

| US class | Field name |
|---|---|
| 106 | Compositions: coating or plastic |
| 148 | Metal treatment |
| 204 | Chemistry: electrical and wave energy |
| 205 | Electrolysis: processes, compositions used therein, and methods of preparing the compositions |
| 210 | Liquid purification or separation |
| 216 | Etching a substrate: processes |
| 250 | Radiant energy |
| 252 | Compositions |
| 257 | Active solid-state devices (e.g. transistors, solid-state diodes) |
| 264 | Plastic and nonmetallic article shaping or treating: processes |
| 313 | Electric lamp and discharge devices |
| 324 | Electricity: measuring and testing |
| 326 | Electronic digital logic circuitry |
| 327 | Miscellaneous active electrical nonlinear devices, circuits, and systems |
| 348 | Television |
| 356 | Optics: measuring and testing |
| 359 | Optics: systems (including communication) and elements |
| 360 | Dynamic magnetic information storage or retrieval |
| 361 | Electricity: electrical systems and devices |
| 365 | Static information storage and retrieval |
| 369 | Dynamic information storage or retrieval |
| 370 | Multiplex communications |
| 372 | Coherent light generators |
| 375 | Pulse or digital communications |
| 385 | Optical waveguides |
| 422 | Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing |
| 423 | Chemistry of inorganic compounds |
| 424 | Drug, bio-affecting and body treating compositions |
| 427 | Coating processes |
| 428 | Stock material or miscellaneous articles |
| 430 | Radiation imagery chemistry: process, composition, or product thereof |
| 435 | Chemistry: molecular biology and microbiology |
| 436 | Chemistry: analytical and immunological testing |
| 438 | Semiconductor device manufacturing: process |
| 501 | Compositions: ceramic |
| 502 | Catalyst, solid sorbent, or support therefor: product or process of making |
| 514 | Drug, bio-affecting and body treating compositions |
| 522 | Synthetic resins or natural rubbers – part of the class 520 series |
| 524 | Synthetic resins or natural rubbers – part of the class 520 series |
| 525 | Synthetic resins or natural rubbers – part of the class 520 series |
| 526 | Synthetic resins or natural rubbers – part of the class 520 series |
| 528 | Synthetic resins or natural rubbers – part of the class 520 series |
| 530 | Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof |
| 536 | Organic compounds – part of the class 532–570 series |
| 544 | Organic compounds – part of the class 532–570 series |
| 546 | Organic compounds – part of the class 532–570 series |
| 548 | Organic compounds – part of the class 532–570 series |
| 549 | Organic compounds – part of the class 532–570 series |
| 600 | Surgery |

development patterns and whether visualization technologies improve a researcher's ability to capture and comprehend patent analysis results more efficiently and effectively.

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