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Nanopatenting patterns in relation to product life cycle

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Abstract

This paper compares the positions of national nanotechnology development efforts based on analyses of patenting from 1994 to 2005. Searching Derwent world patent index files, 19,351 unique patents are collected based on a composite search algorithm. These abstract records are categorized multiple ways — by top patent assignees, by International Patent Classifications, and through content analyses of the "Use" subfield. We classify the R&D activities by using a 3-stage, life cycle, value chain of nano-raw materials, nanointermediates, and nano-products. Profiles of Japanese, American (US), and European (German) emphases show notable differences in concentration and value chain niche. Such characterizations offer significant research management and policy implications.

Keywords: Nanotechnology; Foresight; Patent analysis; Value chain; Innovation management; Text mining; Technical intelligence; Future-oriented technology analyses

1. Introduction

Nanotechnology involves the construction and use of functional structures designed on a molecular scale, with at least one dimension measured in nanometers. On this scale, due mainly to quantum[1] or

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[1] Also called quantum confinement, this refers to the effect caused by the small numbers of atoms which limits the movement of electrons, generating new physical properties in the material.

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surface[2] effects, the physical, chemical, and biological properties of the materials are significantly altered.

From an economic perspective, nanotechnology is currently one of the major foci of research, development, and innovation activities in all industrialized countries [1]. Over the last 8 years, according to Roco [2], global government investment in this area has increased nine-fold: from $432 million in 1997 to about $4.1 billion in 2005. The United States, Japan, and the European Union are investing comparable annual amounts of about $1 billion US (2005) for nanotechnology R&D. The rapid pace at which nanotechnology is moving forward is probably the main reason that it has come to the attention of almost every policy maker and senior manager [3,4].

Although some nanotechnology products have been on the market for several years, it is evident that the society-wide discussion of the advantages and risks of nanotechnology is still at the initial stage. Nonetheless it is clear that the technology draws upon multiple research domains and will affect multiple sectors. Nanotechnology is both "enabling" and "horizontal." According to Grupp [5], enabling technologies are prerequisites for other technologies, products, and processes. Nanotechnology is also a horizontal technology, as it makes possible applications in a number of sectors.

Some authors discuss the disruptive nature of nanotechnology — *e.g*. Walsh and Linston [6] and Kostoff et al. [7]. According to Bower and Christensen [8] when the use of a technology creates products with different performance attributes that may not have been valued by existing customers, it could be called disruptive. Some scientific discoveries alter a technological paradigm to a new competitive one [9–11]. In recent literature, some authors propose methods to identify the development of disruptive technologies. Kostoff et al. [7] state text mine of scientific literature for knowledge discovery to further commercial and governmental uses. Walsh [12] state suggests a model for disruptive technology roadmapping and Fleischer et al. [13] present a methodology to combine technology assessment with roadmapping.

We offer a three-stage, life-cycle framework to provide new perspectives on nano-development. It is based on the notion of a nanotechnology production chain proposed by Lux Research [14], a nanotechnology research and consulting company.[3] This chain is formed on the basis of the value added by the so-called "nano-raw materials," passing through "nanointermediates" and generating "nano-products." Nano-raw materials are any raw material whose nanometric scale confers specific properties to this dimension. Nanointermediates incorporate nano-raw materials, but are not yet aimed at the final user. Nano-products are products available in the market. This classification scheme will be further discussed in reference to the construction of a taxonomy (Section 6). As nanotechnology is "transverse" – involving different economic sectors – this approach seems appropriate. The use of three stages allows us to analyze the nanotechnology *via* a wide screen, without involving details specific to particular businesses.

Future-oriented technology analyses (technology foresight) model the future of a given object of study — *e.g*., a technology in this case. Such studies manipulate information derived using qualitative and/or quantitative techniques [15,16]. The present study was achieved by generating innovation indicators obtained through data and text mining [7,17,18].

The use of technological analyses to help understand the stages of nanotechnology's trajectory is of fundamental importance because the diverse actors involved – researchers, governments, companies and

[2] The surface effects are caused by the larger surface/volume ratio in nanoparticles interfering in chemical properties, as, for example, in reactivity.

[3] The concept of production chain, usual in business management, was introduced to the nanotechnology area by Lux Research. We adopt this construct for our nano analyses as well.

users – need strategic knowledge about nanotechnology's prospects and how to guide them. This study aims to identify the positions of the main countries involved in nanotechnology development, through the observation of the dynamics of patenting over the period 1994 to 2005, when nanotechnology development intensified. We consider such development on three levels:

- on a macro level, national development strategies
- at a meso level, through consideration of competition by sector in the leading countries
- at the micro level, mapping synergy among actors with shared interests.

2. Patents as indicators of innovation

The use of bibliometric indicators can be an efficient method to compare, monitor and analyze research activities in a specific thematic area or a new field [19]. Statistics on patents have been used as indicators of the results of invention-related activities. The number of patents granted to any given company or country reflects technological vigor. An examination of patented technologies may produce indications of the direction of technological changes [20–22].

As with any method, the use of patents as indicators of innovation has limits: innovations do not always correspond to patented inventions, and not all patented invention possesses technological or economic value. That is to say, not all products are patented and not all patents yield products. Considering, however, an area of intense capital mobility like nanotechnology, the dynamics of patenting offer potentially valuable intelligence on emerging products.

A number of studies aim to measure nanotechnology evolution using bibliometric indicators; we selectively note some key approaches and observations. In 1995 Porter and Cunningham [23] discussed the research orientation in nanoscience and nanotechnology, on the basis of an analysis of the publications in two databases: INSPEC, oriented to applied research, and the Science Citation Index, dedicated to fields of basic research. The authors observe that, in both sources, research is oriented to the life sciences, and in particular to biochemistry and organic chemistry. In the applied research arena, the USA and Japan led, along with a strong Chinese presence. They explore SCI capacity for monitoring author citation patterns. Spotlighting the articles that cite the pioneering work by Drexler, a significant increase over time was evident: in 1987 there were 20 studies per year citing this author, in 1993, 49 studies, and, in 1994, 88 publications.

In 2003 Hullman and Meyer offered an important contribution when they published an article reviewing bibliometric studies in nanotechnology [24]. Two studies [25,26] noted the exponential growth in nanoscience publications in the early 90s. Meyer and Persson [27] also discuss the concept of nanotechnology, exploring its interdisciplinary nature in relation to a wide range of scientific and technological fields. Within these studies, an important question arises with respect to the syntax for information gathering. A number of authors [16,19,28–30] use the strategy of retrieving all the documents in a given database that contain terms beginning with the prefix "nano." The occurrence of terms beginning with "nano" does not necessarily signify patents related to nanotechnology, given that these may refer to measurement in nanoseconds, for example. This strategy may tend to inflate the results obtained.

Marinova and McAleer [31] analyzed international nanotechnology patenting through technological strength indicators. This research was based on US patent statistics for 1975–2000 to compile the top foreign patenting countries. They used a nano* search strategy with cleaning procedures and found an exponential increase of patenting with a peak in 1995. Some different types of patent-related indicators were used to classify national nanotechnology patenting performance. They found different national strategies and priorities among the most technologically advanced countries.

This analysis focuses on patenting, as a key indicator of technological innovation prospects. We are fortunate to have access to Derwent patent data, the premier source as indexers rewrite the abstracts and assign classification codes beyond those of the patent authorities to indicate better the foci of the patents. One could go further to explore patent quality metrics, especially citation accrual, but that was beyond the scope of this project. Patent activity is a good base indicator of R&D vigor. The present study used a large sample (18,952 patents related to nanotechnology). The manipulation and analysis of the data reveal trends, not only in countries and sectors, but also within the major players in the nanotechnology market. The innovative contribution is the attempt to classify the degree of development of the nanotechnology chain: nano-raw material, nanointermediate, and nano-products.

3. Methodology

We drew upon the Derwent Innovation Index database, which offers abstracts and additional indexing for the original patent documents of 40 patent-issuing authorities (including the United States, Japan, European Patent Organization, and other leading national patent offices). This database has another useful characteristic: the Derwent Patent Assignee codes, a standardized form of patent assignee.[4]

This study covers a period of 12 years (1994 to 2005, based on date of entry into the database; search performed on Jan. 13–14, 2006). We begin with 1994, as the date that nanotechnology patenting began to be significant [24].

There are many “nano” search formulations, including “snowball” approaches that reach out from unidentified core literatures *via* referencing, for instance [40,41], and multi-modular term search approaches [42–44].

We use a set of 46 terms nominated by experts in nanotechnology (Table 1)[5] [32]. Variations were included to encompass alternative term forms (*e.g.*, quantum dot, quantumdot, quantum-dot) and stemming was used (*e.g.*, nanopartic* where the asterisk captures any word endings). The number of hits for each of the “Top 10” terms, appearing in title or abstract, is indicated.

The total number of patents obtained was 23,446 from 46 discrete searches. These were imported into VantagePoint [www.theVantagePoint.com; also known as Thomson Data Analyzer] and consolidated. Duplicates were removed in VantagePoint to obtain a master set of 19,351 distinct patents. This text mining software also enabled data cleaning (*e.g.*, consolidation of patent assignee name variations) and various analyses.

4. Nanopatenting overview

Overall nanopatenting trends are considered in this section. We present the historical trend by patent priority years for nanopatenting over the 1994–2004 period. Geographic analyses for selected countries are then demonstrated, considering two levels of national patenting vigor. In the last section we analyze the top assignees in a global ranking exploration.

[4] For more information, see http://scientific.thomson.com/support/patents/dwpiref/reftools/companycodes/.

[5] These terms were used in a previous study for the Centro de Gestão e Estudos Estratégicos (CGEE), an organization associated with the Brazilian Ministry of Science and Technology.

Table 1
Nanopatent search terms

Nano terms	
Fullerenes 1808	Nanonetwork
Nanobelts	Nanoparticle 5181
Nanobiology	Nanopatterning
Nanobiotechnology	Nanophase
Nanocatalyst	Nanophotonics
Nanocomposite 1228	Nanopigments
Nanocorns	Nanoporosity
Nanocrystalline, nanocrystal 1517	Nanopowders
Nanodroplets	Nanorods
Nanodrugs	Nanoscale 1185
Nanoelectronics	Nanosieves
Nanoeletromechanical systems (nems)	Nanosize, nanosized 934
Nanoemulsion	Nanospheres
Nanoengineered	Nanostructured, nanostructure 1351
Nanofabrication	Nanotechnology
Nanofibers 808	Nanotemplates
Nanofilters	Nanotribology
Nanohybrids	Nanotubes 4650
Nanoindentation	Nanowires
Nanolithography	Quantum-dots 960
Nanomaterials	Quantum-wires
Nanomedicine	Quasi-crystals
Nanometrology	Spintronics

4.1. Historical trend

Following Wilson [33], we use the priority year in these analyses. Nanopatenting demonstrates exponential growth over this period (Fig. 1). The patent data for 2004 and 2005 are incomplete, although the trend suggests that slowing toward a logistic growth pattern is likely taking place.

4.2. Geographic analysis

By continent, somewhat surprisingly, Asia predominates, with 45% of the patents assigned over the period. It is followed by North America, with 35%; Europe, with 14%; and all others, 6%.

Considering the priority country, it was found that the USA, with 6770, constitutes 99% of North American nanopatents. In Asia, Japan has the lead, with 52% (4631). Germany leads the European Union, with 58% (1701).

Overall, there are 78 countries with nanopatents. Two distinct leading groups stand forth: the top five countries (the USA, Japan, China, Germany and Korea), with more than 1500 patents, and four second tier countries (France, United Kingdom, Russia and Taiwan), with between 200 and 500 patents. Fig. 2 shows countries with 10 or more patents.

The top countries are split in two sets: the first one has countries with more than 1500 patents (USA, Japan, China, Germany and Korea). The second one is formed by top countries with significant patenting.

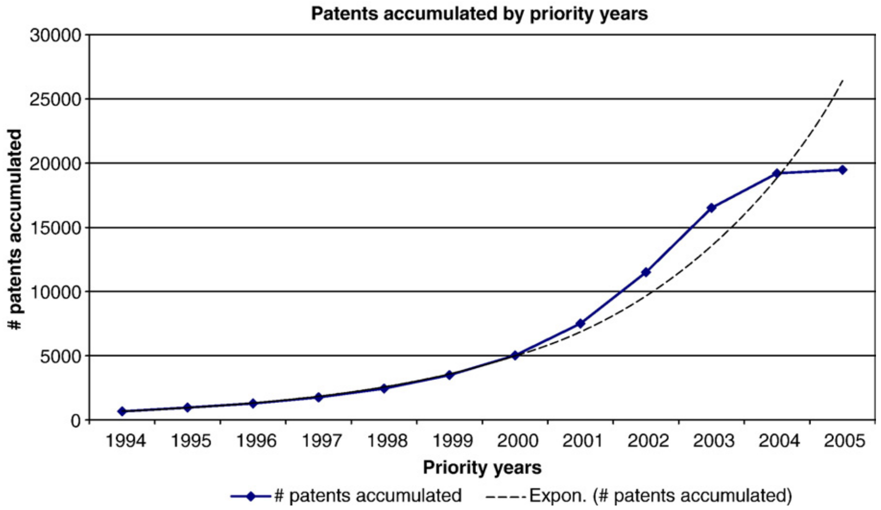

Fig. 1. Cumulative number of patents.

Fig. 3 shows the historical evolution of patenting in the five top countries in three time periods: 1994–1997, 1998–2001 and 2002–2005. Note the huge increase in nanopatenting in China in the latest period-increasing six-fold from the prior period. In comparison, Japan, the USA, and Korea roughly doubled from 1998–2001 to 2002–2005, while Germany maintained the same level of patenting.

The second tier countries demonstrate interesting relative shifts also. The UK and France show similar patent activity levels for 1998–2001 and 2002–05; Russia shows a moderate decline, whereas Taiwan increased three-fold (Fig. 4).

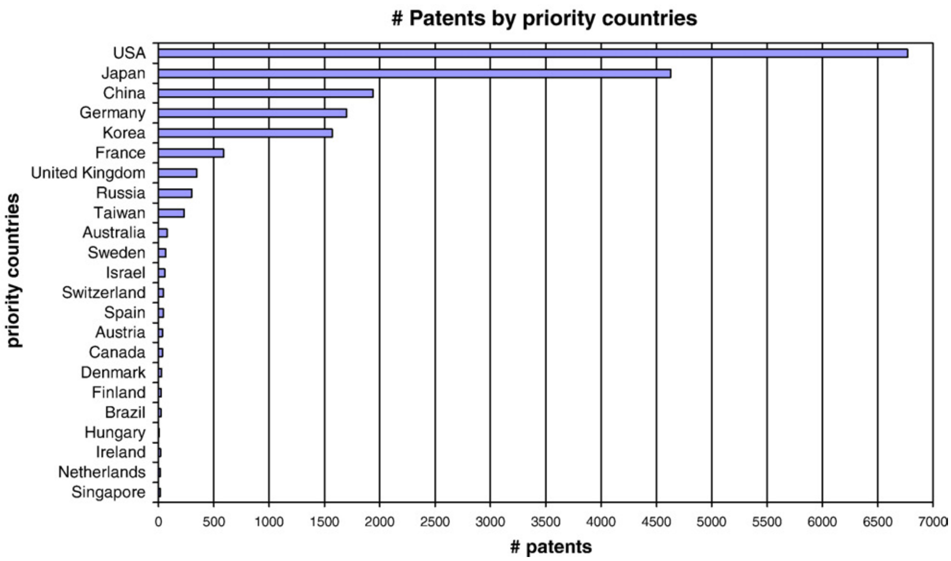

Fig. 2. Frequency of nanopatents by assignee country.

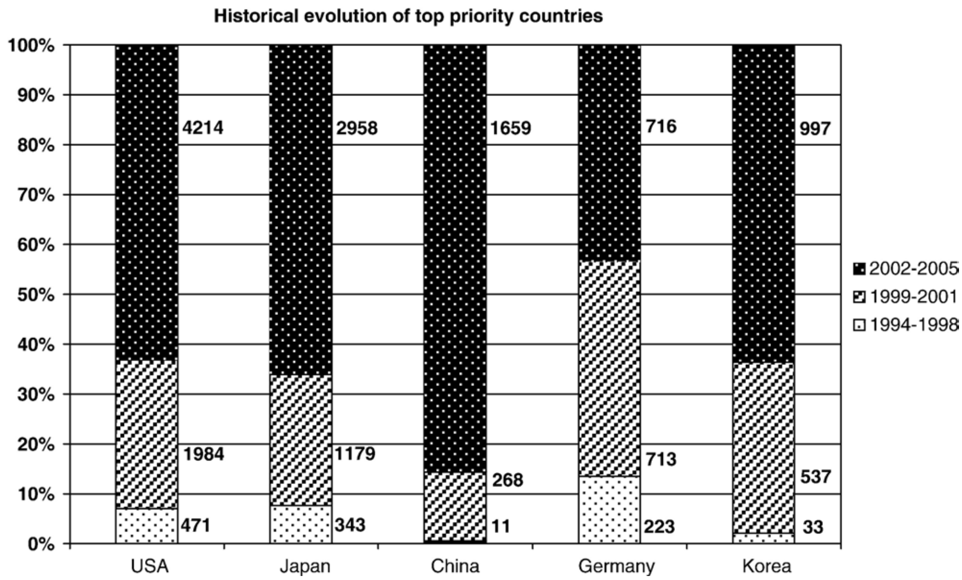

Fig. 3. Historical evolution of nanopatenting in the five leading countries.

4.3. Analysis of patent assignees

We used Derwent patent assignee codes to analyze companies. This field usefully groups the assignees into standard, non-standard and individual assignees. Standard companies are big patenters that regularly file a significant number of patent applications. When the non-standard companies achieve a large number

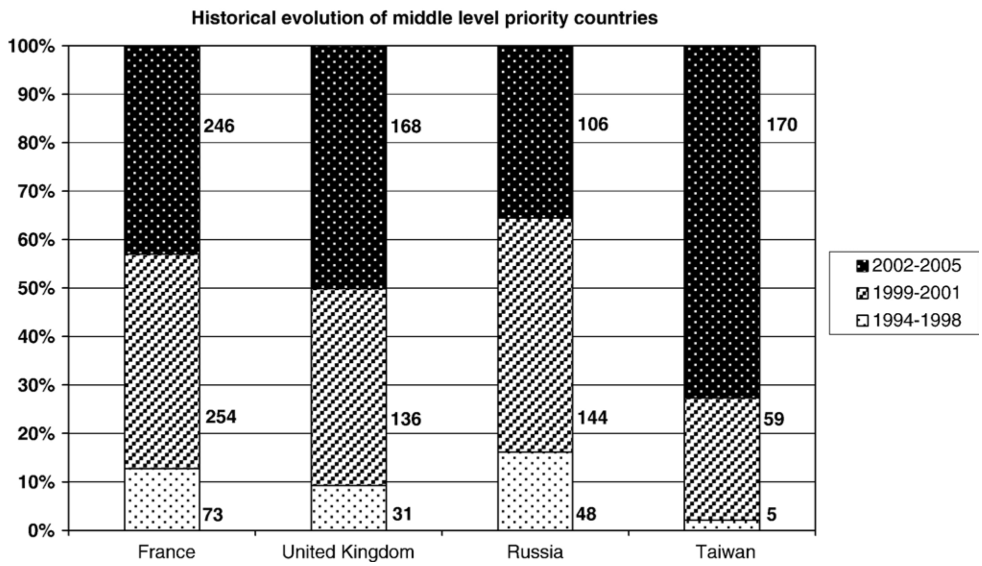

Fig. 4. Historical evolution of nanopatenting in four second tier countries.

Table 2
Leading patent assignees [1994–2005]

#	Patent assignee (patent code)	# of patents	Country	% of nano total	% of assignee total
1	*SAMSUNG SDI CO LTD (SMSU)*	*279*	*Korea*	*1.4%*	*0.24%*
2	*DOKURITSU GYOSEI HOJIN KAGAKU GIJUTSU SH (DOKU-Non-standard)*	*263*	*Japan*	*1.4%*	*8.80%*
3	*SONY CORP (SONY)*	*247*	*Japan*	*1.3%*	*0.26%*
4	*UNIV CALIFORNIA (REGC)*	*197*	*USA*	*1.0%*	*3.41%*
5	*L'OREAL SA (OREA)*	*188*	*France*	*1.0%*	*4.67%*
6	*DOKURITSU GYOSEI HOJIN SANGYO GIJUTSU SO (DOKU-Non-standard)*	*170*	*Japan*	*0.9%*	*1.84%*
7	*DOKURITSU GYOSEI HOJIN BUSSHITSU ZAIRYO (DOKU-Non-standard)*	*153*	*Japan*	*0.8%*	*16.74%*
8	*MITSUBISHI CHEM CORP (MITU)*	*146*	*Japan*	*0.8%*	*0.92%*
9	*LG ELECTRONICS INC (GLDS)*	*137*	*Korea*	*0.7%*	*0.17%*
10	*FUJITSU LTD (FUIT)*	*134*	*Japan*	*0.7%*	*0.27%*
11	*NEC CORP (NIDE)*	*132*	*Japan*	*0.7%*	*0.13%*
12	UNIV QINGHUA (UYQI)	126	China	0.6%	4.50%
13	EASTMAN KODAK CO (EAST)	121	USA	0.6%	0.99%
14	KOREA ADV INST SCI & TECHNOLOGY (KOAD)	117	Korea	0.6%	2.74%
15	INT BUSINESS MACHINES CORP (IBMC)	117	USA	0.6%	0.26%
16	CANON KK (CANO)	109	Japan	0.6%	0.10%
17	IND TECHNOLOGY RES INST (INTE-Non-standard)	107	Taiwan	0.6%	0.24%
18	FUJI PHOTO FILM CO LTD (FUJF)	101	Japan	0.5%	0.10%
19	HITACHI LTD (HITA)	100	Japan	0.5%	1.97%

Note: When the assignee code includes more than one firm (within the same corporation, of course) to be clearer, we chose to put just the name of the one with the most patents.

of patents, they too receive a unique code. Non-standard codes may not be unique; it's important to check the assignee name. The individual patent assignees are not considered in terms of analyses in this work.[6]

After opening the non-standard assignee code groups, we cleaned using a software tool. Some 15,970 assignees were identified, taking into account partnerships among those registering. Around 66% (10,593) are individuals and 34% (5377) are institutions (companies or educational and/or research institutions).

Not surprisingly very few patent assignees have very many nanopatents. The highly skewed curve (Zipf-like distribution) of number of patents *versus* ranked assignee (not shown) shows a sharp knee. Accordingly we focus special analyses on those with at least 0.7% of the nanopatents issued, in other words, more than 50% of the top assignee (in italics in Table 2). Table 2 extends this list to those with over 100 nanopatents.

Among the tops, the strong predominance of the so-called Asian Tigers may be observed, with 7 Japanese, 2 Korean, 1 French and 1 US institution. Table 2 tallies patenting from 1994 to 2005, giving the number of patents assigned and the country, followed by the percentage of patents in relation to the total 19,351 nanopatents. The last column shows the percentage of the assignee's total patenting over this

[6] In this paper we do not analyze the individual assignees, however was noted that two of top ten global nanopatenting assignee are individual inventors from China.

Table 3
Evolution of patenting of the assignees over the period, 1994 to 2005

Patent assignee (patent code)	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
SAMSUNG SDI CO LTD (SMSU)			2			12	51	29	59	81	45	
JAPAN SCIENCE AND TECHNOLOGY AGENCY (DOKURITSU GYOSEI HOJIN KAGAKU GIJUTSU SH)		3	3	4	15	10	25	36	66	66	35	
SONY CORP (SONY)	8	4	4	7	9	17	46	38	49	38	14	1
UNIV CALIFORNIA (REGC)	9	3	3	8	4	7	21	15	37	45	30	8
L'OREAL SA (OREA)	5	6	5	7	22	14	25	33	30	35	4	
NATIONAL INSTITUTE ADVANCED INDUSTRIAL OF SCIENCE AND TECHNOLOGY (DOKURITSU GYOSEI HOJIN SANGYO GIJUTSU SO)							9	31	40	57	33	
NATIONAL INSTITUTE FOR MATERIAL SCIENCE (DOKURITSU GYOSEI HOJIN BUSSHITSU ZAIRYO)							7	8	44	61	33	
MITSUBISHI CHEM CORP (MITU)	5		2	1	6		5	27	36	48	14	
LG ELECTRONICS INC (GLDS)		1		2	2	10	25	27	23	38	7	2
FUJITSU LTD (FUIT)	2	8	6	11	13	8	7	8	35	25	7	1
NEC CORP (NIDE)	8	7	7	6	10	15	14	14	16	12	4	

period — *i.e.*, the degree to which they concentrate on nano-related invention. Notice the wide range with two of the "Dokuritsu" heavily vested in nano, along with L'Oreal, Qinghua University, the University of California and Korea Advanced Institute S&T.

We sought more information on the DOKURITSU institutions.[7] The DOKURITSU GYOSEI HOJIN SANGYO GIJUTSU is the National Institute of Advanced Industrial Science and Technology; the DOKURITSU GYOSEI HOJIN BUSSHITSU ZAIRYO is the National Institute for Material Science; and DOKURITSU GYOSEI HOJIN KAGAKU GIJUTSU SH is the Japanese Science and Technology Agency.

Analyzing the leading nanotechnology patent assignees over the 12 years of the study (Table 3), some institutions have been assigned patents throughout the period, while others show more activity beginning in 1999/2000. We note that Samsung and the "Dokuritsu" are later entrants than most of the leading nanopatenting organizations.

5. Categorizing nanopatents

Patent databases provide standardized terminologies and classification schemes. These permit statistical treatments and analyses [34]. We use two distinct types of information to group nanopatenting activity: (i) International Patent Classification (IPC) coding provides the knowledge areas, and (ii) content analysis allows positioning the nanopatenting along the proposed production chain.

[7] Very little information was found about these organizations, including on internet, but after consulting Japanese external trade organization, we found the English name of these institutes. We are grateful to the kind attention by Sandra Kaneko, Dpto of Public Relations, The Japan External Trade Organization (JETRO) in the Brazilian Office.

Table 4
Leading IPC nanopatent sections

IPC Section	# of patents	% of total nanopatents (%)
Section C — chemistry; metallurgy	5999	31.7
Section B — performing operations; transporting	4302	22.7
Section H — electricity	3454	18.2
Section A — human necessities	2789	14.7
Section G — physics	1872	9.9

5.1. Trend in knowledge areas

IPC coding, created by the World Intellectual Property Organization (Strasbourg Agreement) in 1971, is periodically updated to keep up with technical developments [35]. On January 1st, 2006, its 8th edition,

Table 5
Main ICP subclasses *versus* main uses of the nanopatents

IPC subclass	# patents	Main uses	Position in nanochain value
H01L–semiconductor devices; electric solid state devices not otherwise provided	2870	• Electron device • Semiconductor device • Solar cell	• Nanointermediate • Nanointermediate • Nano-products
C01B—non-metallic elements; compounds thereof	2716	• Carbon nanotube • Fuel cell • Catalyst	• Nano-raw material • Nano-products • Nanointermediate
A61K—preparations for medical, dental, or toilet purposes	1863	• Cancer (treatment, medication) • Cosmetics • drugs	• Nano-products • Nano-products • Nano-products
B82B—nano-structures; manufacture or treatment thereof chemistry	1615	• Carbon nanotube • Electron device • Catalyst	• Nano-raw material • Nanointermediate • Nanointermediate
B01J—chemical or physical processes, *e.g.*, catalysis, colloid chemistry; their relevant apparatus	1520	• Catalyst • Fuel cell • Carbon nanotube	• Nanointermediate • Nano-products • Nano-raw material
G01N—investigating or analyzing materials by determining their chemical or physical properties	1362	• Protein • Nucleic acid • Antibody	• Nano-raw material • Nano-raw material • Nano-raw material
C08K—Use of inorganic or non-macromolecular organic substances as compounding ingredients	1351	• Film • Coat • adhesive	• Nanointermediate • Nanointermediate • Nanointermediate
C08L—compositions of macromolecular compounds	1134	• Film • Coat • fiber	• Nanointermediate • Nanointermediate • Nanointermediate
H01J—electric discharge tubes or discharge lamps	1128	• Field emission display • Carbon nanotube • Display device	• Nanointermediate • Nano-raw material • Nanointermediate
B32B—layered products, *i.e.*, products built-up of strata of flat or non-flat, *e.g.*, cellular or honeycomb, form printing	1043	• Substrate • Coat • Film	• Nanointermediate • Nanointermediate • Nanointermediate

developed with the participation of 55 countries, was launched [36]. This multi-tier system includes the following levels:

1. Sections — *e.g.*, “C” – chemistry, metallurgy
2. Subsections — *e.g.*, chemistry
3. Classes — *e.g.*, C01, inorganic chemistry
4. Subclasses — *e.g.*, C01B, non-metallic elements, compounds thereof
5. Group — *e.g.*, C01B 5/00, water

The IPC orientation is predominantly technical. However, it allows for an invention to be classified on the basis of a double focus, separately or together, according to its technical characteristics or by its application [37]. According to Grilches [38], patent classification is an efficient tool for identifying tendencies in relation to technological development in a multidisciplinary area like nanotechnology. From a macro point of view, when all the nano-patents in the sample are evaluated, more than 50% are classified in sections C and B (Table 4).

A deeper perusal reveals 495 subclasses with a highly skewed distribution. We focus on the subclasses containing more than 5% of the nanopatents. Table 5 (below) shows that the most frequent classification is H01L (Semiconductor Devices; Electric Solid State Devices Not Otherwise Provided For), in which around 15% of all nanopatents are indexed. While section C has the highest frequency, subclass H01L occurs with more intensity. Patents can have more than one classification, and thus different results between the top nanopatent section (C) and the top subclass H01 could be explained because the H section is more concentrated for nano in electricity. It deals mostly with the semiconductor and microelectronics industry, while nano in the C section is more pervasive and dispersed in different applications.

5.2. Chain production position

We devised a taxonomy based on a 3-stage nanovalue chain consisting of: raw materials, intermediates, and final products (Fig. 5).

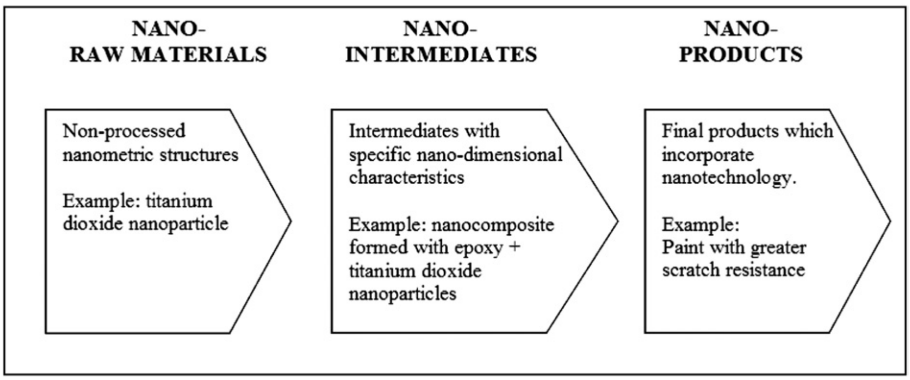

Fig. 5. Nanotechnology value chain — adapted from Lux Research [14].

Other examples of nano-raw materials are carbon nanotubes, nanoparticles, fullerenes (a form of carbon having a large molecule consisting of an empty cage of sixty or more carbon atoms), quantum dots (semiconductor crystals with a diameter of a few nanometers), *etc*. We include any raw material whose nanometric scale confers properties specific to this dimension.

Nanointermediates are situated in the middle of the chain; that is, they incorporate nano-raw materials, but are not yet aimed at the final user. Nanocatalysts, superconducting wires, and optical components improved with nano-raw material are good examples.

Nano-products are available in the market. Examples include sunscreen with nanoparticles possessing a high capacity for the absorption of UV rays and tennis balls with nanocomposites which increase the durability and product quality.

The methodology to place the nanopatents in production chain categories consists of intersecting the IPC subclass with the indicated patent uses. It was done in three steps: text mine "patent use"; segregate the most frequent terms in a selected IPC subclass; arrange these main terms along the value chain. These stages are further explained in the following discussion.

With the aim of analyzing the proposed uses of the patented objects, text mining [39] of the abstract field was undertaken — more specifically, of the sub-field referring to "patent use." VantagePoint software, which uses a Natural Language Processor to extract words and/or noun phrases in a determined field, was employed. This software also offers fuzzy algorithms that allow for the identification of equivalent terms, singular/plural, and typing errors. The algorithms offered can be modified to improve performance.

After thus cleaning the "Use" terms, we select a given set of records (*e.g.*, patents in a given IPC subclass). VantagePoint shows the most frequently occurring terms (in a detail window) for these records and indicates which are statistically most concentrated in these records, compared to frequency in the overall dataset.

We select the most significant terms and judge which of the three nanolife-cycle stages best reflects them (*e.g.*, could this item be sold directly in the marketplace?).

Given the richness of the information contained in a patent document, we chose to cross-reference the terms obtained through text mining of the use field for the nanopatents together with the IPC subclass. We thereby generated a representative table of the main objects of nanotechnology patenting. Table 5 shows the top few uses for the leading subclasses. The last column gives the value-chain stage for each leading use. Nanotechnology development appears to concentrate in the second stage of the value chain, the nanointermediates. Significant development is also present in nano-products, especially in the areas of drugs, cosmetics, and imaging equipment. Other subclasses show heavier emphasis on nano-raw materials.

6. Positioning of three countries along the nanovalue chain

We selected the leading country (see Fig. 2) for each of the three prominent continents in this case North America, Asia and Europe and correspondingly — the USA, Japan, and Germany.

For each country the following methodology was used:

- select top assignees, according to statistic relevance;
- cross IPC subclasses with patent uses based on abstract phrases (according to the previous explanation);

- apply VantagePoint's cross-correlation routine to create the "Knowledge Map," based on IPC commonality;
- Observe institutions with R&D in common areas (clusters);
- Check the most frequently appearing terms by institution, positioning into the value chain categories;
- Estimate the national position along this nanovalue chain.

6.1. United States

Of the 6770 US nanopatents, 9898 were registered by individuals and 6440 by institutions, with large overlapping of individual and institutional assignees. Besides the leading 3 US patent assignees from Table 2 – University of California, IBM, and Eastman Kodak – seven additional institutions are included as assignees on 1% or more of US nanopatents: GE, MIT, Rice University, HP, Intel, 3M e Du Pont. It is interesting that 3 of these 10 are universities, showing the fundamental interaction between R&D institutes and companies.

We then clustered the 10 leading US patent assignees based on commonality of their patent subclasses. We applied VantagePoint's cross-correlation routine to create the "Knowledge Map" in Fig. 6. These

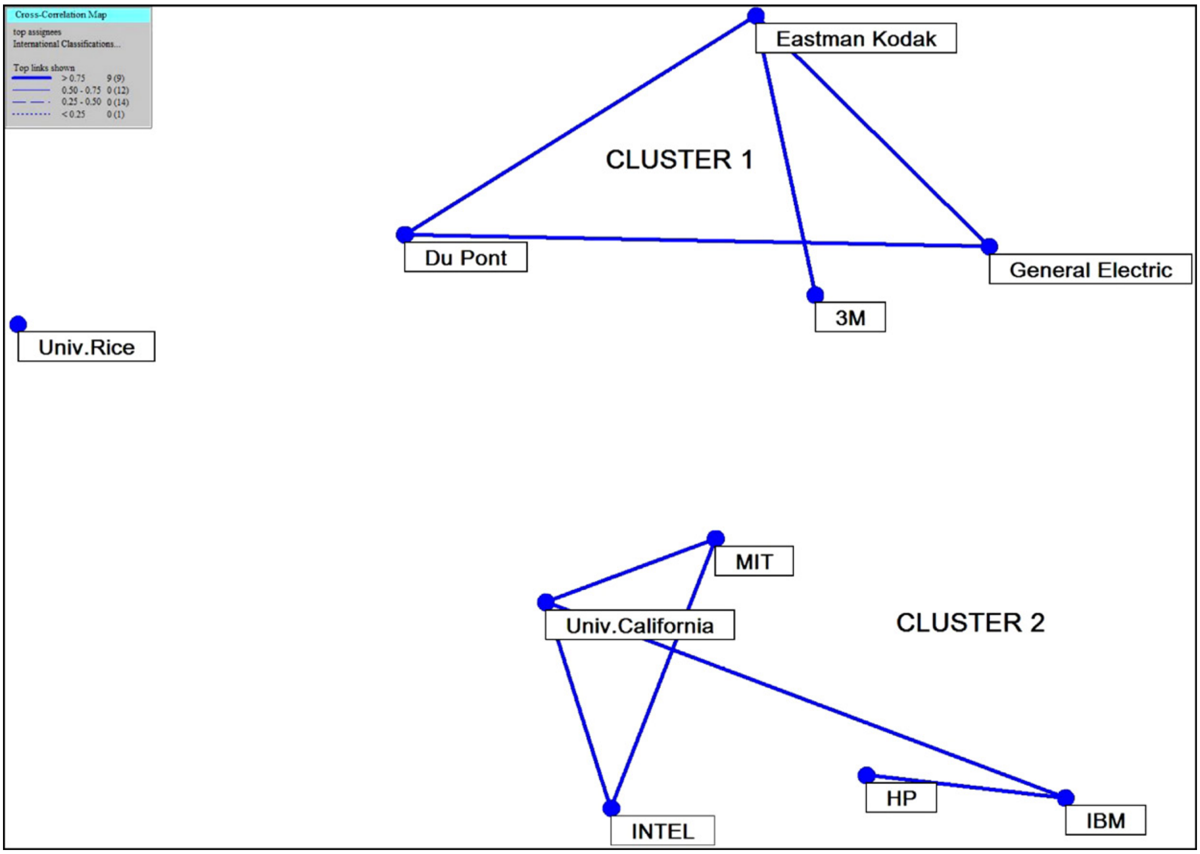

Fig. 6. Knowledge map of leading US patent assignees.

Multi-Dimensional Scaling (MDS) maps locate nodes based on commonality. However to do so fully accurately, one would need a 10-dimensional map for 10 nodes. Hence, VantagePoint provides a path-erasing algorithm to better represent relationships. This generates the links shown among nodes. The five that are strongly connected in Cluster 2 share subclass emphases relatively strongly; similarly, the four that constitute Cluster 1. In other words, these maps provide one perspective on which organizations share nano R&D emphases.

In order to position a country along the nanotechnology chain, we analyzed the content of the abstract "use" field. Cluster 1, shown with the leading IPC subclasses in Fig. 7, involves four important companies:

DUPONT, patenting most strongly in biosensors, photovoltaic devices and memory storage devices; that is, in nanointermediates; and the three other companies mainly positioned in nano-products. EASTMAN KODAK patents heavily in industrial radiography, imaging, and optical systems; GENERAL ELECTRIC, with applications in computers, film, and automobiles; and 3M, involved with dental nano-products: dental adhesive, dental coatings, and orthodontic devices.

USA Cluster 2 consists of three large companies and two research institutions (not broken out in detail). MIT and INTEL have registered patents with the greatest intensity in the nano-raw material and nano-intermediate links of the value chain. MIT's main applications are in proteins, sensors, and tissue engineering, while INTEL has patents in nucleic acid, proteins, and semiconductor devices — all placed in the first two links of the chain. The other three institutions are placed mainly in the intermediate link. The University of California has among its main applications, sensors,

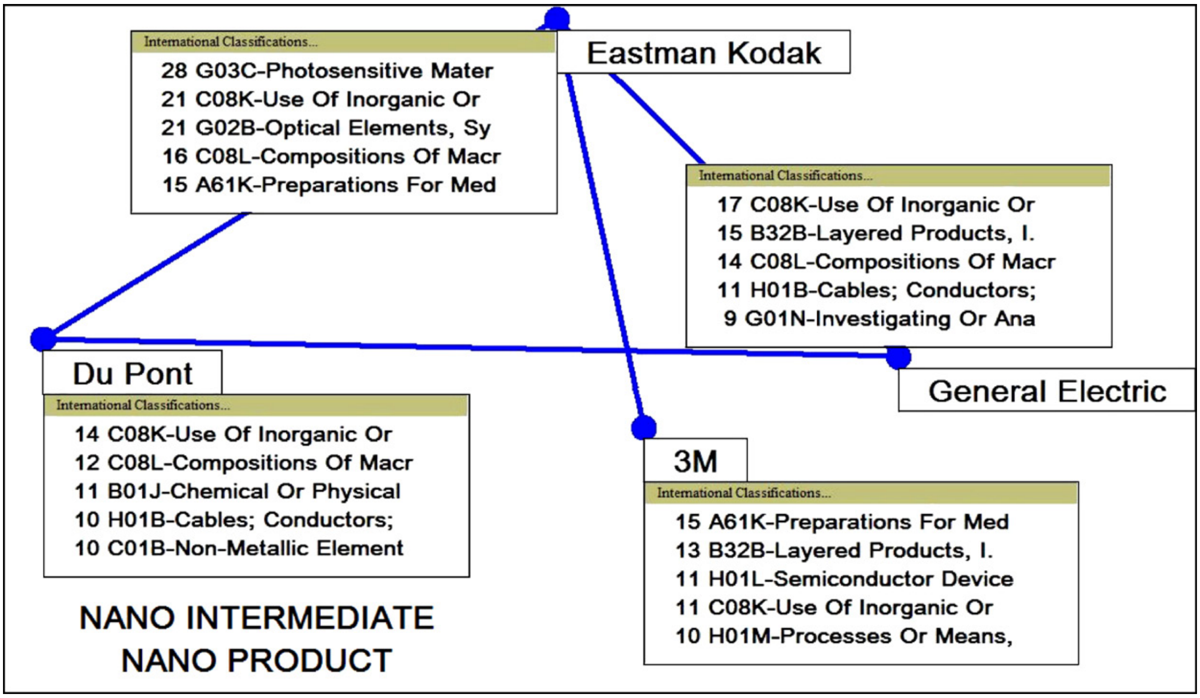

Fig. 7. Cluster 1 — USA.

catalysis, and nucleic acid. IBM focuses on electron devices, integrated circuits, and thin films. HP keys on sensors and memory and electronic devices. We classify these applications largely as nanointermediates.

The US shows diffusion of its nanopatenting across the three links of the chain, with some concentration in nanointermediates.

6.2. Japan

We treat the 4631 Japanese patents analogously to what we did with the American patents. We focus on the nine main Japanese patent assignees (those holding 2% or more of their patents) and the leading IPC subclasses represented by their patents.

The resulting Knowledge Map, based on commonality of subclasses among the leading assignees' patents, indicates a single large cluster, involving seven of the nine main companies (Fig. 8), with two individual "outlier" nodes (Fujitsu, Fuji Photo Film).

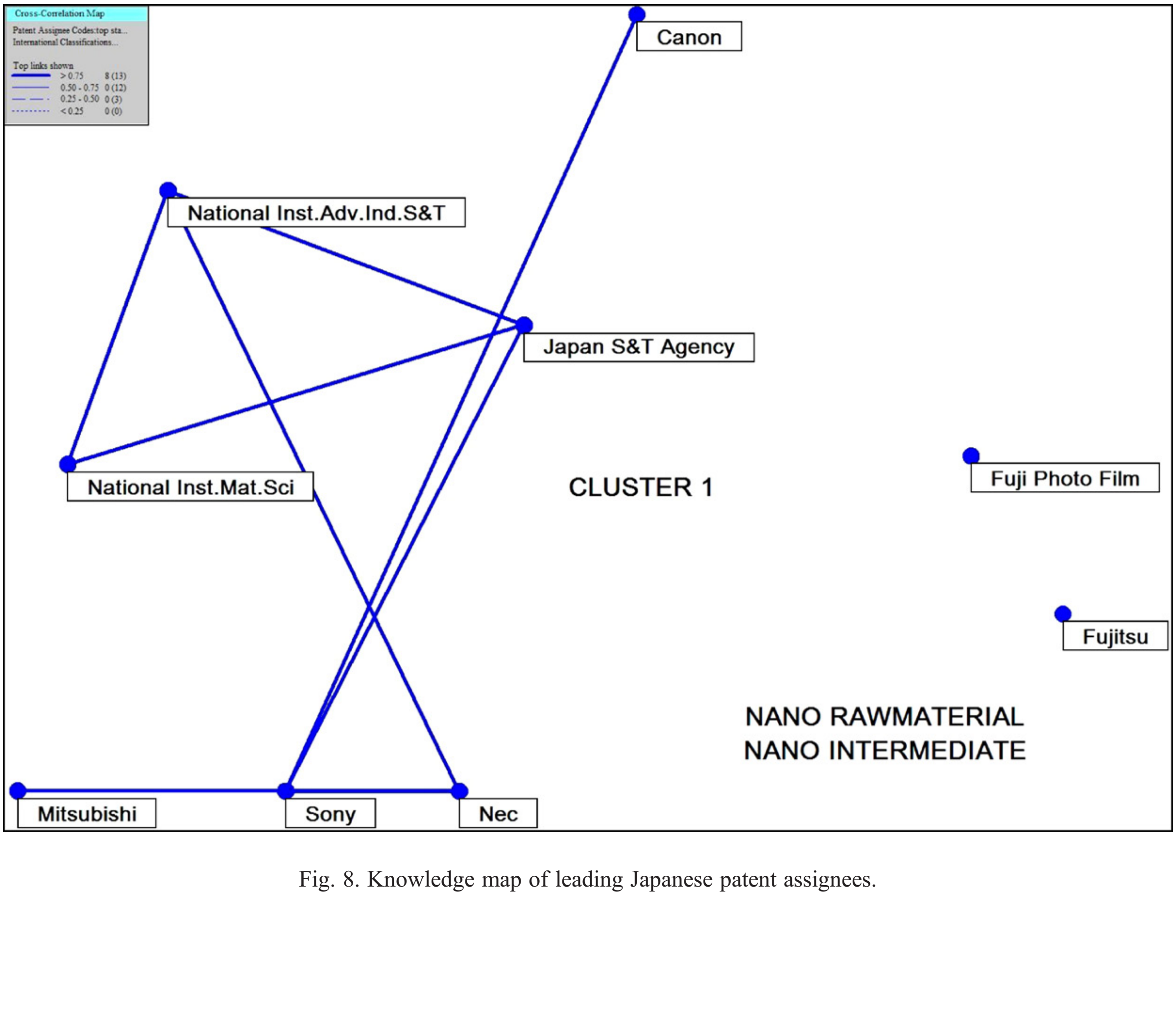

Fig. 8. Knowledge map of leading Japanese patent assignees.

The most frequently appearing "use" terms for the Cluster 1 assignees are:

- Canon
  - Electron device
  - Optic device
  - Carbon nanotube
- National Institute Advanced Industrial of Science and Technology
  - Carbon nanotube
  - Electron device
  - Catalyst
- Japan Science and Technology Agency
  - Carbon nanotube
  - Electron device
  - Catalyst
- National Institute for Material Science
  - Catalyst
  - Semiconductor device
  - Optic devices
- Mitsubishi
  - Fullerene
  - Catalyst
  - Semiconductor device
- Sony Corp
  - Fuel cell
  - Electrochemical device
  - Carbon nanotube
- Nec Corp
  - Carbon nanotube
  - Electron device
  - Semiconductor device

We locate these Japanese nanopatents mainly in the first stages of the nanotechnology value-chain — nano-raw materials and nanointermediates.

6.3. Germany

Germany leads patenting in the European Union, with 1701 patents, which represents 60% of the nano-patents in that region. Of those, 1482 are assigned to individuals, and 1877 by companies, with overlapping. Again, we focus on the institutions (11) with 2% or more of the German nanopatents over the sample. And, again, we map these based on shared IPC subclasses among their patents (Fig. 9). This indicates a principal cluster involving five of the main German companies, and two smaller clusters of two companies each.

Analysis of Cluster 1 reveals that the majority of these nanopatents are oriented towards final products, as may be observed in the list of use terms:

- BAYER
  - Plastic
  - Coating
  - Glass
- BASF
  - Furniture
  - Door
  - Window
- INST NEUE MATERIALIEN GEMEINNUETZIGE
  - Coating
  - Building
  - Plastic
- DEGUSSA
  - Plastic
  - Ink
  - Ceramic
- CREAVIS GES TECHNOLOGIE & INNOVATION
  - Fuel cell
  - Electrolyte membrane
  - Textile

The second cluster, formed by Max Planck and Hoechst, seems to be dispersed in terms of applications, because the first one works with catalysts, sensors, and cosmetics; and Hoechst is patenting in new

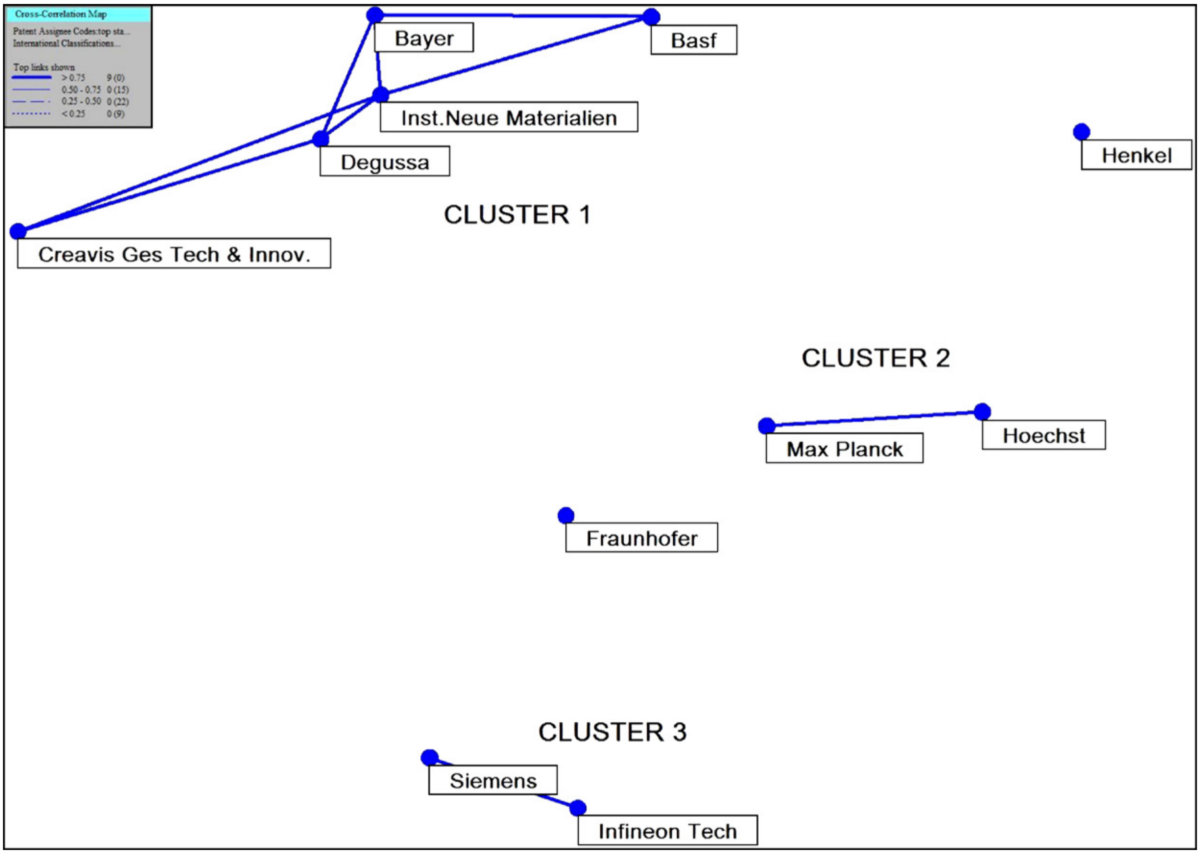

Fig. 9. Knowledge map of nanopatents in Germany.

fullerene derivatives, catalysts, and optoelectronic components. These companies have in common the IPC B01J class (chemical or physical Processes — *e.g*., catalysis, colloid chemistry; and related apparatus). These indicate that they are patenting in processes.

The cluster 3 largely involves nanoproducts such as electrodes, solar cells and wiring structures in the case of SIEMENS, and nanointermediates such as microelectronics, electronic components and semiconductor chips in the case of INFINEON.

7. Conclusions

This article contributes a method for characterizing the state of nanotechnology development of main institution of the country. A significant set of 19,351 patents related to nanotechnology was examined, using text mining. We analyzed a combination of IPC subclass and content descriptive of the intended "use" of the patents. We used this information to map shared emphases of leading patent assignees in each of three countries — the US, Japan, and Germany.

We considered the patent concentrations in terms of a three-stage value-chain model. This enabled us to characterize institutional and national nanopatenting in terms of its targets: nano-raw materials, nano-intermediates, or nano-products.

Through three case studies it was observed that the dynamic of innovation in this emerging area demonstrates differing patenting patterns. The country which leads in the number of nanopatents, the USA, presents a situation in which its inventiveness is spread relatively thinly among many actors and spread across the three links in the value chain. Approaching the topic from another perspective, Japan stands out as the country with the institutions most actively patenting nano-developments. Those patents appear to emphasize the beginning and middle of the chain — nano-raw materials and nanointermediates. Germany, although presenting a lower volume of patent documents, appears to be targeting the greatest added value from its inventions, strongly emphasizing nano-products.

These results raise interesting considerations for companies pursuing nanotechnology. To what degree is one's nano R&D coherently focused? What are its value chain targets — raw materials, intermediates, or products? Certainly consideration of nano-development must also relate to other company priorities. It may be worthwhile to combine nano R&D, other R&D, and products together in integrated roadmapping exercises to help focus company efforts to generate the greatest expected value. We have focused on nanotechnology. However, the notion of life cycle analyses that distinguish value-chain stages should work for other technologies as well.

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