The trends and geography of nanotechnological research

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This paper presents a study of trends in nanotechnology, indicating regional development efforts, based on analyses of scientific publications from 17 countries, divided in two sets: seven key countries (USA, France, Germany, Japan, United Kingdom, Canada and Spain) and ten competitor-countries (Brazil, India, China, Australia, South Africa, Korea, Singapore, Malaysia, Israel and Mexico), from 1994 to 2004. A search in the Web of Science database was undertaken, utilizing 51 terms selected by experts in nanotechnology. A master dataset with almost 140,000 registers was created and scientific indicators were produced through data and text mining tools and a competitive intelligence approach.

In the key countries, it was possible to discern the quantity of publications from the USA (21,769), followed by Japan (10,883). Within the per-country analysis, in the case of the USA, for example, the most frequently used terms are "nanoparticulates", "nanotube", "quantum dot", "nanocrystal" and/or "nanostructure". China has the best position in the competitor countries. Brazil is the best in the Latin America, and represents 5.7% of the competitor-country publications, with 1066 papers, and "quantum dot" is the most frequently term used for the representative Brazilian universities.

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Introduction

Nanotechnology involves the construction and use of functional structures projected on an atomic or molecular scale, with it least one their dimensions measured in nanometers. On this scale, mainly because of quantum[1] or superficial[2] effects, the behaviour of matter is markedly different from the generally understood and commonly accepted concepts. The laws related to chemical, biological, electrical, magnetic and other properties on the nanoscale are different from those which apply to matter on a macroscale; it is the laws of quantum physics which rule in the "nanoworld".

A number of economic sectors are being affected by nanoscience/nanotechnology, with applications in the areas of health, chemicals and petrochemicals, computers, energy, agriculture, metallurgy, textiles and environmental protection, amongst others. The Asia-Pacific Economic Cooperation organization – APEC, identifies the business opportunities offered by nanotechnology in three directions: molecular engineering, derived from biotechnology, electronic technology, based on semiconductors, and equipment and processes founded on new materials (Tegart 2004).

Evaluating the potential of nanotechnology up to the year 2020, Roco (2004) has affirmed that its development from exploratory concepts to wider applications behaves in a way similar to the transitions in information technology between 1960 and 2000 and in biotechnology between 1980 and 2010. Thus, the monitoring and mining of tendencies in scientific advances in this area has become fundamental to the search for opportunities in research, development, innovation potential and future business, both in leading and emerging economies, a fact which underlines the research presented in this article.

In this context and in order to demonstrate the potentiality of the foresight methodology to support the decision making process in several areas, this paper presents a study of trends in nanotechnology, indicating regional development efforts, based on analyses of scientific publications from 17 countries, divided in two sets: seven key countries (USA, France, Germany, Japan, United Kingdom, Canada and Spain) and ten competitor-countries (Brazil, India, China, Australia, South Africa, Korea, Singapore, Malaysia, Israel and Mexico), from 1994 to 2004.

The nanoworld – generation of new systems and/or products

Nanotechnology, according to Walsh (2004), may be seen as a disruptive technology, as its use generates products with performance attributes which cannot be evaluated by consumers.

According to Roco (2004), the first nanotechnology generation – beginning in 2000 – was the discovery and production of relatively simple components with nanometric particles, nanotubes and nanofilms. A major transition was observed most recently, in 2005, heading in the direction of active nanostructures and nanosystems. Nanostructures change their states (morphology, form, mechanics, electrical properties, magnetism, etc.) during their operation. Examples would be a mechanical activator which could change its dimensions, or nanoparticles for drug delivery which change their morphology and chemical composition. Such changes are increasingly more complex the larger the structures and systems, and involve multiple phenomena.

This technology has proven to be attractive to a number of economies, a fact which is emphasized when one considers that as early as 2002, a report commissioned by the UK Ministry of Science and Innovation identified 30 countries as then undertaking activities and plans related to nanotechnology (UK Advisory… 2002). Three years later, Roco (2005) presented international benchmarks for R&D in nanotechnology, demonstrating that at least 60 countries have initiatives in this area. The nanoworld is growing rapidly.

The potential of technology may be evaluated relative to investments in research, development and innovation, and is currently one of the main focuses of activity in industrialized countries (Baker & Aston 2005). Europe, Japan and the USA have invested approximately equal amounts of government funds, estimated to be around US$1 billion for 2005 (Foster 2005; Schulte 2005).

Various studies have aimed to estimate the size of the global market for materials, products and processes based on nanotechnology. Currently, there appears to be a convergence of estimates in the region of US$1 trillion for the period 2010 to 2015, according to market analysts from the Mitsubishi Research Institute in Japan, the Deutsche Bank in Germany and Lux Research in the USA.

The mining – identification of trends in scientific development

The research[3] took as reference the Web of Science database. For the purpose of mining scientific production in nanotechnology over an eleven-year period (1994–2004), 51 distinct terms were used, selected by Brazilian experts in this area[4]. The advanced data recovery resources offered by the database were utilized, with the aim of expanding and enriching the results.

The search terms were focused on the countries which are the focus of this analysis, divided into two groups: seven key countries (the USA, France, Germany, Japan, the UK Canada and Spain) and ten competitor-countries (Brazil, India, China, Australia, South Africa, Korea, Malaysia, Israel and Mexico).

Macro-indicators were generated for each group of countries, using data and text mining resources, furnishing a general and regional view of scientific production of the complete range of nanotechnology. For the leaders of the key countries, the USA and Japan, as well as for the leaders of the competitor countries, China (general) and Brazil (Latin America), the following were identified:

- The total number of articles published per year (1994 to 2004) and the trend in publication, relative to the most frequently used nanotechnology terms for each year;
- The total number of articles using the top terms, with identification of the authoring institutions with the greatest number of publications on the terms;
- The main journals in which the leading authoring institutions with the highest frequency terms publish their articles.

Table 1. Frequency of terms.

Nanoterm	%
nanocrystal	14.28%
nanoparticle	13.51%
nanostructures	10.06%
quantum dots	9.13%
fullerenes	9.02%
nanotubes	8.25%
nanocomposite	5.02%

A global vision of scientific development in nanotechnology

For the period 1994 to March 2004, 139,618 articles containing the 51 search terms were found for all the countries involved. With regard to the key countries, this group represents around 40% of the total (55,704 articles), while the competitor-countries group presents a slighter participation, at 14% of the total (19,644 articles).

It may be observed that the term "nanocrystal" shows the highest frequency, at 14.28%, followed by "nanoparticle", which leads to the perception of a high level of diversity of publication in this area. Table 1 presents the terms with a frequency of more than 5%.

Macro-trend of scientific development in key countries

The leadership of the United States in publication is evident, with almost double the number of articles compared to the second-placed country, Japan. It is also worth noting that the USA and Japan together account for 58% of publications among the key countries. Fig. 1 shows the participation, by percentages, of nanotechnology publications of the key countries over the ten years covered by the study.

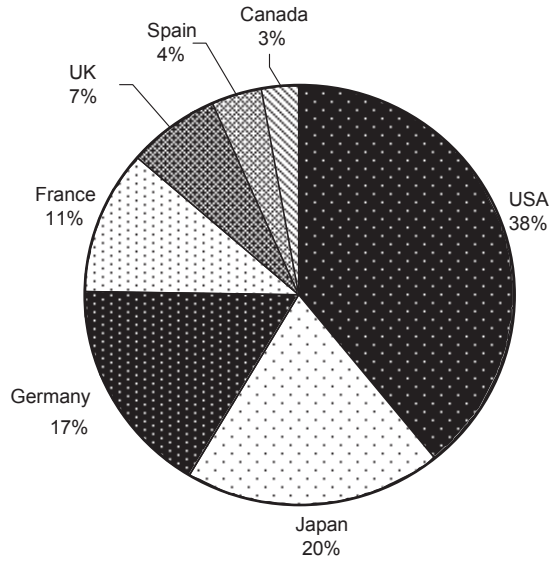

Fig. 1. Nano scientific papers published per key country (1994–2004).

It can be observed in Fig. 2 that there was exponential growth in the number of articles published in relation to nanotechnology during the period 1994 to 2002, in the order of 650%. The analysis for

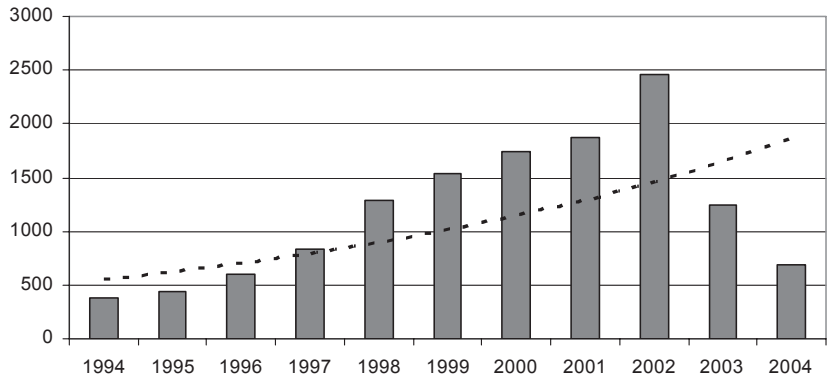

Fig. 2. Historical evolution of nanotechnology publishing in the key countries.

Table 2. Highest frequency terms in articles published in the USA by year of publication – 1994/2004.

USA – total number of articles = 21,769			
Year of publication [no. of articles]	Top terms [no. of articles per term]	Year of publication [no. of articles]	Top terms [no. of articles per term]
1994 [636]	fullerene [113] nanocrystal [59] quantum dot [49] quantum wire [40] nanomaterial [32]	2000 [2723]	nanotube [283] nanoparticulate [280] quantum dot [246] nanocrystal [187] nanostructure [166]
1995 [788]	fullerene [100] nanocrystal [85] nanostructure [64] nanomaterial [53] quantum dot [41]	2001 [3342]	nanoparticulate [432] nanotube [355] quantum dot [266] nanocrystal [241] nanomaterial [208]
1996 [1054]	nanocrystal [104] fullerene [103] quantum dot [88] nanostructure [76] nanoparticulate [68]	2002 [4310]	nanoparticulate [602] nanotube [527] quantum dot [299] nanocrystal [265] nanostructure [242]
1997 [1213]	nanocrystal [146] fullerene [98] nanoparticulate [94] quantum dot [90] nanostructure [83]	2003 [2517]	nanoparticulate [731] quantum dot [291] nanocrystal [125] nanofiber [91] nanostructure [90]
1998 [1748]	nanocrystal [182] nanotube [156] nanoparticulate [154] nanostructure [121] nanomaterial [98]	2004 [1224]	nanotube [184] nanoparticulate [161] nanosize [71] nanocrystal [69] nanostructure [67]
1999 [2214]	quantum dot [215] nanocrystal [214] nanoparticulate [203] nanotube [172] nanostructure [135]		

the last two years, 2003 and 2004, offers a lesser degree of confidence, as the input of data into the database is sometimes delayed for a period of time.

The USA – world leader in nanotechnology scientific publication

The term "nanocrystals" appears among the five most frequent terms in the articles published between 1994 and 2004, the only such term to appear across the whole period. In Table 2, it can be seen that, from 1996 to 2003, the frequency of the term "nanoparticles/ nanoparticulates" demonstrated growth of 930%, appearing in 700 articles in 2003. The term "nanotubes" is amongst the five with the highest frequency in the period 1998 to 2002, with growth of 296%. Another term which stands out amongst the five with the highest frequency is "quantum dot", at 200 articles per year between 1999 and 2003.

It is of note that, despite a high frequency of publication per term, there is a degree of dispersion among the institutions authoring the articles. The five top institutions with publications containing the term "nanoparticles / nanoparticulates", represent only 16% of the total articles published on this topic (2787).

Looking at the five US institutions with the greatest number of articles by top term, it can be seen that three of these institutions present a greater degree of consistency in terms of scientific production related to the search terms. These are: the University of California, Berkeley, Illinois University and the Massachusetts Institute of Technology. This data can be observed in Table 3.

Table 3. Distribution of institutions with the largest number of publications by highest frequency term amongst US articles – 1994/2004.

United States – total number of articles = 21,769			
Top terms [no. of articles]	Top institutions [no. of articles]	Top terms [no. of articles]	Top institutions [no. of articles]
nanoparticulate [2787]	Georgia Inst Technol [106] Northwestern Univ [100] Univ Illinois [87] Washington Univ [81] Univ Calif Davis [69]	nanostructure [1277]	Univ Illinois [56] MIT [46] Univ Connecticut [46] Univ Calif Berkeley [44] Arizona State Univ [36]
nanotube [1913]	NASA [130] Rice Univ [117] Univ Kentucky [113] Univ Calif Berkeley [95] Rensselaer Polyt. Inst – Pittsburgh [93]	nanomaterial [1090]	Cornell Univ [53] USAF [50] Univ So Mississippi [39] Michigan State Univ [34] Univ Michigan [33]
quantum dot [1687]	Univ Calif Sta Barbara [193] Arizona State Univ [105] Univ Illinois [92] Univ Texas [86] Univ Michigan [82]	nanosize [1038]	Univ Calif Berkeley [39] Univ Illinois [34] Penn State Univ [34] MIT [30] Univ Florida [29]
nanocrystal [1677]	Univ Calif Berkeley [114] MIT [81] Oak Ridge Natl Labs [69] Argonne Natl Labs [64] Georgia Inst Technol [57]	fullerene [1013]	Univ Notre Dame [76] Rice Univ [69] Univ Calif Los Angeles [56] Univ Miami [42] NYU [40]

Japan – second-place leader in nanotechnology publication

Articles on "nanocrystals" appear amongst the five highest frequency terms for those published between 1994 and 2004, with an oscillation between 20 and 150 articles per year. This term is the only one which appears throughout the period studied, a tendency also observed in the USA for the same term. It was further observed that from 1997 to 2003 the term "nanoparticles / nanoparticulates", demonstrated strong growth, on the order of 833%, attaining a total of more than 270 articles in 2003. The term "nanotubes" appears amongst the five highest frequency terms in the period 1994–2004. Another term which stands out in the five high frequency terms for the period 1999–2003 is "quantum dot", which reached its publication peak in 2000, with 189 articles. The term "fullerene" appears amongst the high frequency terms for the period 1994–2002, and also had its publication peak in 2000, with a total of 136. The preceding data is presented in Table 4.

Table 5 shows that the University of Tokyo leads in publication related to the term "quantum dot", with around 22% of the articles on this theme produced in that country. This university is present among the five top authoring institutions for the majority of the higher frequency terms: "nanoparticles/nanoparticulates", "nanotubes", "nanostructures", "quantum wire" and "nanoscale". The second most frequent term, "nanoparticles/nanoparticulates", demonstrates the leadership of Osaka University, with more than 10% of the articles. It is of interest to observe that the NEC Corporation Ltd. is among the five institutions with the highest frequency of articles on "nanotubes", contributing 82 of 947 articles.

Comparative view of the higher frequency terms of the two leading key countries

Table 6 presents the higher frequency terms for the two leading key countries and the institution with the highest number of articles on that term. It also identifies which journals had the highest frequency of articles on these terms.

The two highest frequency terms are "nanoparticles/nanoparticulates" and "quantum dot", with the two highest publication journals for these two countries being:

Table 4. Highest frequency terms in articles published in Japan by year of publication – 1994/2004.

Japan – total number of articles = 10,883			
Year of publication [no. of articles]	Top terms [no. of articles per term]	Year of publication [no. of articles]	Top terms [no. of articles per term]
1994 [275]	fullerene [38] quasi-crystal [30] quantum wire [21] nanocrystal [19] quantum dot [12]	2000 [1456]	quantum dot [189] fullerene [136] nanotube [126] nanocrystal [126] nanoparticle [105]
1995 [286]	fullerene [63] quantum wire [25] nanocrystal [24] quantum dot [18] quasi-crystal [10]	2001 [1766]	nanotube [179] nanoparticle [173] nanocrystal [156] quantum dot [156] fullerene [122]
1996 [489]	fullerene [76] nanocrystal [67] quantum dot [32] quantum wire [30] nanotube [26]	2002 [2076]	nanotube [282] nanoparticle [195] quantum dot [157] nanocrystal [141] fullerene [105]
1997 [585]	fullerene [70] quantum dot [65] nanocrystal [54] nanoparticle [33] quantum wire [26]	2003 [974]	nanoparticle [275] quantum dot [136] nanotube [47] nanostructure [39] nanocrystal [28]
1998 [1084]	quantum dot [154] nanocrystal [95] fullerene [79] quantum wire [66] nanoparticle [61]	2004 [564]	nanoparticle [78] nanotube [76] nanocrystal [27] fullerene [25] nanocomposite [24]
1999 [1328]	quantum dot [157] fullerene [120] nanotube [113] nanoparticle [105] nanocrystal [92]		

- *Applied Physics Letters* – experimental or theoretical articles with applications in physics or contemporary technologies.
- *Journal of Physical Chemistry B* (JPC:B) – articles on materials (nanostructures, macromolecules, bio-physical chemistry and physics-chemistry in general), as well as articles on structures and properties of surfaces and interfaces.

Macro-trend of scientific development in the competitor countries

Within the group of competitor countries, strong leadership belongs to China, which in the last ten years published 51% of articles. Brazil is in fifth place, with 5% of articles published, following Korea (14%), India (11%) and Israel (7%). Account-

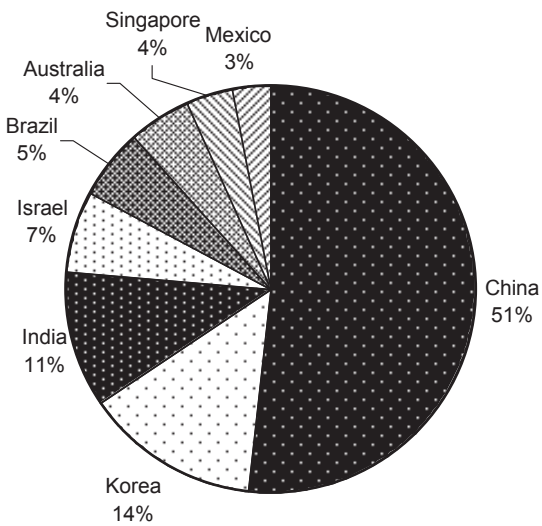

Fig. 3. Nano scientific papers published in competitor-countries (1994–2004).

Table 5. Distribution of Japanese institutions with the highest number of publications by high frequency term – 1994/2004.

Japan – total number of articles = 10,883			
Top terms [no. of articles]	Top institutions [no. of articles]	Top terms [no. of articles]	Top institutions [no. of articles]
quantum dot [1096]	Univ Tokyo [239] Univ Tsukuba [134] Hokkaido Univ [93] Riken[1] [88] Tohoku Univ [79]	nanostructure [394]	Tohoku Univ [41] Univ Tokyo [35] Osaka Univ [34] Japan Sci Technol Corp [23] Univ Kyoto [21]
nanoparticle [1054]	Osaka Univ [111] Tohoku Univ [72] Univ Tokyo [63] Kyushu Univ [62] Tokyo Inst Technol [59]	nanocomposite [344]	Osaka Univ [73] Tohoku Univ [29] Natl Ind Res Inst Nagoya [27] Toyota Technol Inst [16] Natl Inst Adv Ind Technol & Sci [14]
nanotube [947]	Univ Tokyo [103] Meijo Univ [97] Nec Corp Ltd [82] Tohoku Univ [78] Tokyo Inst Technol [52]	quantum wire [335]	Univ Tokyo [65] Hokkaido Univ [51] Osaka Univ [41] Electrotech Labs[2] [32] Japan Sci Technol Corp [24]
fullerene [840]	Nagoya Univ [116] Tohoku Univ [91] Tokyo Metropolitan Univ [76] Osaka Univ [74] Univ Kyoto [73]	nanoscale [294]	Tohoku Univ [33] Osaka Univ [30] Univ Tokyo [29] Tokyo Inst Technol [15] Univ Kyoto [15]
nanocrystal [829]	Tohoku Univ [167] Osaka Univ [65] Univ Tsukuba [53] Univ Tokyo [43] Tokyo Inst Technol [42]	nanowire [119]	Natl Inst Mat Sci [26] Hokkaido Univ [15] Japan Sci Technol Corp [9] Electrotech Labs [9] Osaka Univ [8]

Table 6. Leaders of the key countries – USA and Japan: top terms versus most-published institutions versus the respective journals.

United States		
Top term	Top institution	Highest frequency journals of the top institution
nanoparticule/ nanoparticulate	Georgia Inst Technol	Abstracts of papers of the American Chemical Society Journal of Physical Chemistry B
Japan		
2 top terms	Top institutions	Highest frequency journals of the top institutions
quantum dot	Univ Tokyo	Applied Physics Letters Physical Review B
nanoparticule/ nanoparticulate	Osaka Univ	Journal of Physical Chemistry B Applied Physics Letters

ing for less than 5% of articles are Australia, Singapore and Mexico, as shown in Fig. 3.

As to follow, Fig. 4 demonstrates that there was exponential growth, on the order of more than 1500%, in the number of nanotechnology articles published by the competitor-countries between 1994 and 2002. The analysis for the last two years, 2003 and 2004, offers a lesser degree of confidence, as the input of data into the database is sometimes delayed for a period of time.

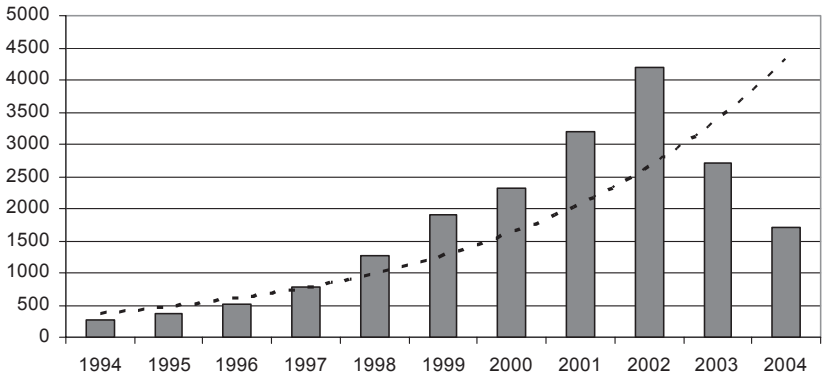

Fig. 4. Historical evolution of nanotechnology publishing in the competitor countries.

China – leader in nanotechnology development among the competitor-countries

The strong leadership of China among the competitor-countries is evident. In Table 7 it can be observed that the term "nanocrystals" is of high frequency in the articles published between 1994 and 2002, with growth of more than 1000% between 1994 and 2002. Between 1998 and 2002, the topic "nanoparticles/nanoparticulates" experienced growth of 530%, reaching a total of more than 360 articles in 2003. "Nanotubes" appears among the highest frequency terms for 2000–2002, accounting for more than 100 articles per year in this period.

It can be seen in Table 8 that the Chinese Academy of Sciences is present among the leading institutions with the largest number of articles for all the highest frequency terms, demonstrating this institution's diversity in areas of nanotechnology research. "Quantum dot" represents around 45% of the articles published on this term.

Table 7. Highest frequency terms in Chinese articles by year of publication – 1994/2004.

China – total number of articles = 10,112			
Year of publication [no. of articles]	Top terms [no. of articles per term]	Year of publication [no. of articles]	Top terms [no. of articles per term]
1994 [141]	nanocrystal [26] fullerene [15]	2001 [1635]	nanocrystal [209] nanoparticulate [185]
1995 [197]	fullerene [31] nanocrystal [30]		nanotube [173] nanomaterial [117] nanowire [100]
1996 [270]	nanocrystal [50] fullerene [35]	2002 [2187]	nanotube [298] nanocrystal [271]
1997 [374]	nanocrystal [82] fullerene [53]		nanoparticulate [251] nanomaterial [156] nanowire [147]
1998 [642]	nanocrystal [131] nanoparticulate [69] fullerene [57]	2003 [1457]	nanoparticulate [366] nanocrystal [126] quantum dot [107]
1999 [966]	nanocrystal [179] nanoparticulate [102]		nanowire [95] nanorod [91]
2000 [1241]	nanocrystal [190] nanoparticulate [133] nanotube [106] quantum dot [100]	2004 [1002]	nanotube [151] nanoparticulate [133] nanocrystal [102] nanomaterial [85]

Table 8. Distribution of Chinese institutions with the highest number of publications by high frequency term – 1994/2004.

China – total number of articles = 10,112			
Top terms [no. of articles]	Top institutions [no. of articles]	Top terms [no. of articles]	Top institutions [no. of articles]
nanocrystal [1396]	Chinese Acad Sci [348] Univ Sci & Technol China [245] Jilin Univ [120] Nanjing Univ [117] Acad Sinica [111]	nanowire [495]	Chinese Acad Sci [142] Univ Hong Kong [68] Univ Sci & Technol China [67]
nanoparticulate [1291]	Chinese Acad Sci [429] Jilin Univ [109] Peking Univ [108]	fullerene [469]	Chinese Acad Sci [110] Fudan Univ [58] Peking Univ [58]
nanotube [927]	Chinese Acad Sci [263] Tsing Hua Univ [170]	nanostructure [358]	Chinese Acad Sci [116] Univ Sci & Technol China [46] Acad Sinica [46]
nanomaterial [579]	Chinese Acad Sci [179] Univ Sci & Technol China [78] Univ Hong Kong [46]	nanosize [323]	Chinese Acad Sci [101] Tsing Hua Univ [34]
quantum dot [565]	Chinese Acad Sci [258] Univ Hong Kong [58]	nanorod [259]	Univ Sci & Technol China [92] Chinese Acad Sci [50]

Brazil – Latin American leader – relative position in nanotechnology development

Brazilian publication of articles on nanotechnology accounts for only 5.7% of the total number published by the competitor-countries over the last ten years, a statistic which demonstrates the need for a policy of support and effective incentives for research, development and innovation in this area.

Of note is that "quantum dot" is present among the highest frequency terms for nine of the ten years under study, with its highest degree of publication in 2002, with 37 articles. 2002 saw around 28% of the publications for the ten-year period (Table 9).

It should be noted that the two Brazilian institutions which stand out in the publication of articles with high-frequency terms are the University of São Paulo (USP) and State University of Campinas (Unicamp). In addition, both institutions are leaders in the publication of articles on the highest frequency term, "quantum dot", with both contributing more than 24% of articles on this topic. With regard to "nanoparticles/ nanoparticulates", the University of Brasília (UnB) is the leader, with 24%, followed by the University of São Paulo (USP), with 19% of the articles published on this topic (Table 10).

Global view of the highest frequency terms for the leader amongst the competitor-countries

Table 11 presents, for the leader amongst the competitor countries, the highest frequency terms, along with the institution with the highest number of articles on those terms, and identifies which journals most frequently published articles on the terms. It can be observed that the two terms appearing with the highest frequency in Chinese publications: "nanoparticles/ nanoparticulates" and "nanocrystals", for which the journal with the highest frequency for China is also amongst the journals serving the same function amongst the key countries: *Applied Physics Letters* – experimental or theoretical articles with applications in physics and contemporary technologies.

Final considerations

The seven key countries (the USA, Japan, Germany, France, the UK, Spain and Canada) have demonstrated dynamism in nanotechnology research over the last ten years, with more than 50 thousand articles published. The competitor-countries (China, Korea, India, Israel, meanwhile, have entered the arena, although in an as yet emerging

Table 9. Highest frequency terms in Brazilian articles by year of publication – 1994/2004.

Brazil – total number of articles = 1066			
Year of publication [no. of articles]	Top terms [no. of articles per term]	Year of publication [no. of articles]	Top terms [no. of articles per term]
1994 [11]	nanocrystal [3] nanotube [1] nanosize [1] quantum wire [1] fullerene [1]	2000 [136]	quantum dot [19] nanotube [12] nanoparticulate [11] nanomaterial [8] nanocrystal [5]
1995 [18]	quantum dot [3] nanotube [2] fullerene [2] nanocrystal [2] quantum wire [1]	2001 [168]	quantum dot [13] nanoparticulate [12] nanocrystal [12] nanotube [10] nanomaterial [10]
1996 [28]	quantum dot [9] fullerene [3] nanocrystal [3] nanostructure [2] nanotube [1]	2002 [297]	quantum dot [37] nanotube [27] nanocrystal [25] nanoparticulate [22] nanostructure [14]
1997 [49]	quantum dot [5] nanoparticulate [4] nanocrystal [4] nanosize [3] quantum wire [3]	2003 [127]	quantum dot [35] nanoparticulate [34] nanocrystal [6] nanostructure [3] nanomaterial [3]
1998 [62]	quantum dot [8] quantum wire [6] nanotube [3] nanoparticulate [3] nanocrystal [3]	2004 [54]	nanocrystal [5] nanoparticulate [4] nanotube [4] quantum dot [4] nanostructure [3]
1999 [116]	nanocrystal [12] nanoparticulate [9] quantum dot [8] nanomaterial [6] nanostructure [5]		

manner, with a total of slightly less than 20 thousand articles over the same period.

Amongst the key countries, the USA stands out, while for the competitor countries the leadership rest with China, whose publications total almost one half of the number produced in the USA. The volume of Chinese publications exceeds that of Germany, third-ranked among the key countries. Also of note is that fact that the combined publications of the competitor-countries Korea and India equal those of the sixth-placed key country, Spain.

In regard to the search terms, "nanoparticles/nanoparticulates" is among the highest frequency topics for both the key countries and the competitors, with the Journal of Physical Chemistry (JPC-B) of the American Chemical Society (ACS) being the journal with the highest frequency of publication for both groups of countries. "Nanocrystals" is the term with the second highest frequency.

In the case of Brazil, Latin American leader, it is of note that the term "quantum dot" is the one which appears most frequently. It is observed that nanotechnology research in Brazil is still in its early stages, compared to the other competitor countries. The University of São Paulo (USP) and the State University of Campinas (UNICAMP) are the Brazilian institutions with the highest profiles in this area.

Finally, in regard to Brazil, it should be noted that, in an effort to generate effective support for the scientific and technological development of nanotechnology, the Industrial, Technological and Foreign Trade Policy, launched in 2004 by the Brazilian government, places nanotechnology, along

Table 10. Distribution of the institutions with the highest number of publications by high frequency terms in Brazilian articles – 1994/2004.

Brazil – total number of articles = 1066			
Top terms [no. of articles]	Top institutions [no. of articles]	Top terms [no. of articles]	Top institutions [no. of articles]
quantum dot [141]	Univ. São Paulo [35] Univ. Estad. Campinas [34] Univ. Fed. São Carlos [26] PUC – Rio de Janeiro [20] Univ. Brasília [12]	nanostructure [46]	Univ. Fed. São Carlos [12] Univ. São Paulo [7] Univ. Fed. RioGrandeSul [6] Univ. Brasília [5] Univ. Estad. Campinas [4]
nanoparticulate [100]	Univ. Brasília [24] Univ. São Paulo [19] Univ. Fed. São Carlos [14] Univ. Estad. Campinas [13] Univ. Fed. Goias [10]	quantum wire [36]	Univ. São Paulo [9] Univ. Estad. Campinas [8] Univ Sao Francisco (1) [5] Univ. Fed. Ceará [3] Univ. Fed. São Carlos [3]
nanocrystal [80]	Univ. Estad. Campinas [25] Univ. São Paulo [21] Centro Bras. Pesq. Fisicas [9] Univ. Fed. São Carlos [9] Lab Nacl Luz Sincrotron [6]	nanosize [21]	Univ. Fed. RioGrandeSul [5] Univ. Fed. Rio de Janeiro [3] Univ. Fed. São Carlos [2] Univ. Fed. Paraiba [2] Centro Bras. Pesq. Fisicas [1]
nanotube [67]	Univ. Fed. Minas Gerais [43] Univ. Fed. Ceará [22] Univ. São Paulo [9] Lab Nacl Luz Sincrotron [5] Univ. Estad. Campinas [5]	fullerene [19]	Univ. Estad. Campinas [7] Univ. Fed. Minas Gerais [3] Univ. Fed. Goias [3] Univ. Fed. Rio de Janeiro [2] Univ. São Paulo [2]
nanomaterial [47]	Univ. São Paulo [20] Univ. Estad. Campinas [11] Univ. Fed. Paraná [8] Univ. Est. Paulista [7] Univ. Fed. São Carlos [6]	nanowire [13]	Lab Nacl Luz Sincrotron [8] Univ. Estad. Campinas [6] Univ. Fed. Rio de Janeiro [1] Univ. Fed. Minas Gerais [1] Univ. Fed. São Carlos [1]

Table 11. Leadership of China amongst the competitor countries: top terms versus most-published institution versus the respective journals.

China		
2 top terms	Top institution	Highest frequency journals of the top institution
nanocrystal	Chinese Acad Sci	Journal of Applied Physics Applied Physics Letters
nanoparticule/ nanoparticulate		Chemical Physics Letters Journal of Material Chemistry

with biotechnology and biomass/renewable energy, amongst those areas considered keys to the future.

NOTES

[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.

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

[3] The research presented here forms part of a study undertaken by the research group under the leadership by titular professor Adelaide Antunes, of the Sistema de Informação sobre a Indústria Química (SIQUIM) laboratory of the EQ/UFRJ, in response to the demand of the Centro de Gestão e Estudos Estratégicos (CGEE), a centre connected to the Ministry of Science and Technology (MCT) (Antunes et al. 2004).

[4] The terms were proposed by specialists at the State University of Campinas, referred by the CGEE/ MCT.

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