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Nanotechnologies for textiles, fabrics and clothing: an overview of the scientific literature on the topic

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ABSTRACT: Aim of the present work is the analysis of the scientific literature on the topic of Nanosciences and Nanotechnologies applied in the field of the study and production of fabrics, textiles and clothing. A dataset, obtained with a specific methodology, is analysed in order to describe the features and the evolution of this field. Several features of the dataset are highlighted in the study. Results on numbers and trends of the different features are presented and discussed, and at the end of the work conclusions on the evolution of scientific production on the topic are presented.

KEYWORDS: Nanotechnologies; Nanosciences; Textiles; Fabrics; Clothing; Scientific literature.

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CONTENTS

INTRODUCTION

Nanotechnologies and Nanosciences (NST from now on) are since the 1990s a relevant scientific-technological field. They are important also for industrial innovation. This is true as they can be fruitfully exploited to innovate existing products, or to create new ones. NST are in fact an interdisciplinary domain, deriving from classic scientific fields in hard and applied sciences: Chemistry, Physics, Biology, Engineering of materials. Thus NST can be considered as a joint evolution of these fields, but paying specific attention to a specific character of the materials: that of its dimensions. In fact the name of nanosciences is due to the fact that they are targeted at the study of the peculiarities of matter at the scale of nanometers; nanotechnologies in turn tackle the technological use of the findings of nanosciences. Thus NST are the branch of sciences and technologies acting on the materials in the boundary of the nanometers, in specific between 1 and 100 nanometers.

What makes NST even more interesting is – as partly above described – their character of interdisciplinariety and cross-domain with respect to the classical scientific-technological fields. This peculiarity makes more difficult their analysis, but is also the cause of their effect on a wide variety of materials and objects. In fact the NST approach can be applied to a high number of materials, processes, objects, products, very different among them from the technological and productive point of view.

Among the main fields touched by nanotech applications are nanoelectronics, nanomaterials (such as carbon nanotubes, fullerenes and graphene, nanoparticles, nanocomposites materials), bio-nanotechnologies.

One of the fields which can benefit from the effective innovative approach of NST is that of textiles, fabrics and clothes. NST have had in recent times the power to introduce several technological innovations in this field, and has the chance to introduce even more in the next future. The field is extremely relevant from the point of view of its economic turnover. Thus it is easy to predict that any innovation improving the quality of existing produced good, or allowing to produce new one, can have relevant economic effect. From this consideration derives the interest on studying the applications of NST to fabrics and clothing. In specific the perspective of the present work tackles NST from a pre-innovation point of view. That is, it performs the analysis of the scientific literature discussing those topics that involve the application of NST to fabrics and clothing. An analysis of this kind is relevant in that it can indicate the paths followed in the recent past by scientific research, and thus show what will be the main directions of innovative activities in the next future. Textile industry is one of the largest and most pervasive ones, and presents an extremely wide number of consumer applications. Thus the analysis of its scientific basis is important for its implications.

Finally, such a study is even more important as, to the best of my knowledge, no such analysis has been performed so far.

Thus it is relevant to fill this knowledge gap and to highlight the specificities of this field. The following of the present work is organized as follows. Section 2 contains a literature overview describing the different types of applications of NST to textiles and clothes. Section 3 presents the methodology used in the present work to build the dataset at the basis of the study. Section 4 describes the obtained results, while fifth and last section discusses the results.

LITERATURE OVERVIEW

The present literature overview aims at introducing the scientific literature discussing the most relevant applications of NST to textiles and clothes. In fact to the best of my knowledge no previous scientific studies have been performed to analyze the scientific literature of this field. Moreover this literature overview is relevant in that it allows to shortly define and describe some of the applications that will be discussed in the following sections of the present work.

NST are by definition extremely pervasive, and thus the possibilities they offer to improve or create materials and applications are almost limitless. This is particularly true for the textile industry, as also textiles are extremely pervasive themselves, and find application on a vast number of products. Sawhney et al. (2008) address NST application in textiles.

They describe several categories of improvements dictated by NST in the field: improvement of fiber/yarn manufacturing; progress in fabric finishing; representative products. Among the reviewed NST applications are: the use of Carbon nanotubes (CNT) to reinforce yarns and to produce conductive fibers; surface fiber improvement via deposition of nanoparticles (NP); the development of nano-composite fibers; NST surface modification to improve finishing of fibers; NST-based products for outdoor, military and engineering.

A similar review is that performed by Coyle et al. (2007), which specifically focuses on the topic of NST applied to smart textiles, and thus stressing different topics and applications with respect to the above described paper. In particular they address NST applications in healthcare and fashion, besides those, above mentioned, in military and sports/outdoor. Smart textiles in such fields can be projected to offer supplementary protection to cold and moisture, or integrate sensors for different functions. These sensors can for instance monitor the heart rate of a runner or the life parameters of a person suffering of a chronic illness, or the conditions of a soldier in extreme environmental or hazardous situations. Also fashion application – such as light emitting fibers for creating patterns – can be envisaged for smart textiles.

Greßler et al. (2010) perform a more comprehensive and general overview on the topic of nano textiles. It is relevant the discussion of the possible ways to perform a nanotech manufacturing process on fibers and textiles. Authors distinguish between the use of nanoparticles in the manufacturing (e.g. incorporating them in the polymer used to produce fibers), the use of nanostructures (e.g. nanofibers or nano-porous fibers) or the “nano-refining” of the surface of fibers via, e.g., the deposition of nanoparticles. Authors also list comprehensively the properties of nanotextiles and the nanomaterials exploited to obtain them, and describe some relevant applications. For instance the use in dirt- and water-repellent textiles or the use as filters for pathogens. Their analysis did count at that time more than 80 "nano-tex" products yet available on the market. Finally, also a reflection on the possible impacts on health and the environment are made.

Other reviews focus instead on more specific topics. It is the case for instance of the work of Dastjerdi and Montazer (2010) who focus on the anti-microbial properties of the textiles modified with inorganic nano-structured materials. Such materials are mainly oxides (such as Titanium dioxide in nanoparticles or nanotubes) or metals (such as Silver nanoparticles). Other materials (for instance carbon nanotubes, nanocomposites, other metals such as Gold, Zinc or Copper) are also used to the purpose of creating substrates able to kill bacteria, rather than grow them.

Som et al.(2011) instead study the environmental and health effects of nanomaterials exploited in the production of textiles, as well as used in external coatings of buildings. In particular what authors explore are the effect of a possible release of engineered nanomaterials from the substrates that host them, focusing on existing applications. In particular their work is based on the effects of nanoparticles of different materials, as the above cited Titanium dioxide, Carbon nanotubes and Silver, as well as Zinc oxide, Alumina, Silica. Authors point out the existing knowledge gap on the possible dangerous effects of such nanomaterials, as well as on the rate of their release from substrates.

There exists also a wide bibliography discussing – from the point of view of hard sciences – specific NST application on fibers and textiles. Some examples are cited here.

The review paper of Tung and Daoud (2011) summarizes findings and concepts relative to the realm of NST-enhanced self-cleaning fibers. The paper carefully describes the different methods and physical-chemical paths able to impart self-cleaning properties to the fibers. The different nanomaterials that are applied to the scope are also described. Also side-by effects, such as UV protection and anti-odor effect, are described in the work.

A similar topic is that treated by ul-Islam et al. (2013). In their review on green-chemistry produced biopolymers a section is devoted to the future prospects of nanotechnology which is "playing an extraordinary role in the functional finishing of textiles" (p. 5256). Authors' main concern is the introduction of green chemistry principles in NST. In particular one of the reviewed functionalization of fibers is the application of nanoparticles made with biopolymers. Such nanoparticles display properties such as higher stability and improved antimicrobial action.

But a wider perspective on the antimicrobial agents for textiles is that offered by Simoncic and Tomsic (2010). Among the several biocide compounds reviewed in the article are nanoparticles of noble metals and metal oxides. Besides this also organic-inorganic nanocomposite polymer network on the surface of textiles are described.

In the range of NST application in textiles a relevant place is the production of non- or low-flammability fibers and objects.

The topic is reviewed by Horrocks (2013). NST have improved this field since the 1990s.

Nanoparticles included in polymeric fibers have been studied to this end. More in specific studies have deepened the role of nanoclays to this end.

From the point of view of technologies exploited to produce nanofibers a relevant place is that of electrospinning.

The scientific literature on the topic of cellulose acetate nanospun nanofibers has been reviewed by Konwarh et al. (2013). All the different types of techniques to obtain electrospun materials, as well as the applications of such materials, are reviewed.

For instance bioactive substances can be immobilized in the nanofibers, drugs can be loaded inside the materials or photocatalytic self-cleaning fibers can be produced. Temperature-adaptive materials, materials for bioremediation or antimicrobial fibers can also be prepared, always depending on the type of nanomaterials included in the nanofibers during the electrospinning process.

Finally, nanotech produced or enhanced fibers, as well as smart textiles, pose safety problems due to possible risks inherent to their nature. Such risks are studied in the work of Köhler and Som (2014), in particular with regard to environment, health & safety and sustainability. According to the authors' results it is important to have a life cycle perspective to assess the impact of such materials on environment and the humans.

Safety strategies should be implemented together with the technology innovation process in order to minimize risk mitigation costs.

The reviewed literature covers many (but obviously not all) topics related to the enhancement of textiles, fibers and cloths with NST products.

Besides offering a general overview on the topic introducing the following experimental section of this work this overview is targeted at introducing those scientific-technological areas that have been highlighted by the experimental activity and that will be discussed in the conclusions.

METHODOLOGY USED TO BUILD THE DATASET

Data on scientific products have been retrieved on Elsevier SCOPUS® online database .

This database has some advantages with respect to other similar web-based databases. First of all it encompasses a much wider number of publications: it reviews in fact more than 22,000 titles, mostly peer review journals but also trade publications, book series and conference papers.

Moreover it has an efficient data retrieval system, that can be exploited in order to build complete datasets.

In order to build the dataset exploited in the present work the following procedure has been performed.

Data extraction activity has been performed on July 2015. First of all a query has been built and applied in the "Advanced search" tab of the Scopus website main page.

The query is:

TITLE-ABS-KEY((nanotech* OR nanosci*) AND (fabric OR textile OR cloth OR woven)).

The search has been done on Title, Abstract and Keywords of the scientific products present in the database (using the Scopus search code TITLE-ABS-KEY). Search terms have been combined with Boolean operators AND and OR. Thus all the documents containing "nanotech" or "nanosci" (the asterisk meaning "any other group of characters afters the indicated ones, thus comprising terms such as nanotechnology, nanotechnological, nanoscientific, nanoscience, etc.) and any other of the specific, textile-world-related terms have been included in the first draft of the database.

The search query is more conservative than the most general possible, using "nano*" instead of "nanotech* OR nanosci*" as search term addressing NST. Nevertheless it has been chosen in order to avoid including too many spurious scientific products in the dataset obtained by SCOPUS®. The chosen option seemed, while projecting the search strategy, adequately conservative and inclusive at one time, thus appearing the most reliable one. The effort was to include any document related to the topic studied in the present work without being too general. The query rendered a total of 1,546 documents, starting from 1998 to 2015. This dataset has been the basis for the second stage of the data retrieval procedure. In fact all the 1,546 have been screened, controlling title, keywords and abstract, as well as the source, in order to control whether their content did really fit with the topic of the research. In fact it might be possible for instance that terms like "fabric" do not refer to textile fabrics but to, e.g. fabrics of computers for network applications. Also those publication referring to e.g. arrays of nanotubes organized in fabrics that have nothing to do with textiles have been withdrawn from the dataset.

Moreover, also those publications discussing nanotech in textiles but related to general issues discussing possible future advancements and not touching specific topics have been withdrawn. Finally, the same fate befell to those publication containing reports of national or international Fairs, or describing research institutions or firms and companies.

The outcome of this second stage resulted in a dataset containing 739 scientific products, dating from 2000 to 2015. This is the dataset that has been analyzed in the experimental work to realize this paper: the analysis is described in the next section.

DATASET ANALYSIS AND RESULTS

The first analysis performed over the 739 scientific documents is relative to the evolution of their publication year. Results are shown in table 1 and figure 1. It is easily seen that the number of scientific publications grows quickly in the first years and peaks in 2008.

Then numbers decrease for a couple years and finally become stable. It must be noted that 2014 results must be considered as still incomplete, as the query has been performed in the middle of the following year. It is well known in fact that databases take a long time to receive data from publishers and to become complete.

This trend – a growth in the first years and a following decrease – may have a simple explanation. Authors have highlighted in the past the fact that NST patents and scientific literature have witnessed a decrease in number after some years of inflation (Schmoch and Thielmann, 2012; Coccia et al., 2012; Finardi, 2012). Thus the trend presented by literature on NST application in the field of textiles and clothing might simply reflect the most general trend of NST scientific literature. On the other side there might be present a decrease of scientific interest on the specific topic. The most general explanation – decrease of interest in research coupled to a most general decrease of publications on NST – is feasibly the most probable explanation of the trend.

A further analysis is that performed on the evolution of the number of citations received by the articles in the dataset across time.

In order to perform this analysis, first of all the number of citations received by each of the articles has been collected from the dataset. Then the citations have been summed up according to the publication year of the cited article. After this stage the number of received citations have been divided times the number of cited articles published in the year.

At the last stage the number of obtained citations have been divided times the lifetime in years of the cited articles.

That is, analytically:

$$N_{cit_Y} = \frac{\sum_{i=1}^{N} CIT_i / N}{(2015 - Y)}$$

where Y is obviously the publication year in object. Results are reported in table 2 and in figure 2.

The graph in figure 2 easily shows that the evolution over time of average citations present a scattered profile. The year presenting the highest number of average citations is 2010. This is feasibly due to the presence of some highly cited papers in the dataset.

In fact the value of average citations is almost double the value of the second year in order of magnitude, 2008.

The lowest values are those presented in the first two years of the dataset (2000 and 2001).

This is feasibly due to the lower interest existing at the beginning of research activities in the field. Values lower that before in the last years (2011-2014) are instead easily explained by the classical model of accumulation of citations, where it is well explained that scientific product in hard and applied sciences present a peak of citations some years after their publication (see for instance Finardi, 2014, for a discussion on the topic).

A relevant analysis performed on the dataset relates to specific research topics developed in the scientific literature in the context of the general topic of the present work.

This analysis has been performed on the titles of the scientific products present in the database in the following way. Scientific products have been divided according to their publication year.

Then titles have been selected, and all the words in the title have been conflated in a single table and then ordered alphabetically. Finally relevant keywords have been searched for and accurately counted. Results of this analysis are reported in tables 3 and 4 and in figures 3, 4 and 5.

15 relevant keywords or group of keywords have been selected in this analysis.

These ones have been roughly classified into three groups: “materials”, “techniques and characters” and “uses”. Table 3 reports absolute values (number of occurrences per year) of the keywords or groups of keywords, whereas table 4 reports the values expressed as faction of the total number of scientific products in the specific year.

This last indicator is the most relevant one, as it assesses the relevance of the topic with respect to the total scientific production in the field of the year. In this way it is possible to follow the evolution of the relevance of the topic in the general field of NST application in textiles and clothing bypassing the bias due to the evolution of the total number of scientific products with time.

In the first group, “materials” the most relevant chosen topics are: (nano)Composites; (nano)Silver; Metals and oxides (encompassing the search terms Al2O3 – Alumina / SiO2 – Silica / TiO2 – Titania / MgO – Magnesia / Copper / Gold / Palladium / Nickel); (carbon)Nanotube / CNT / MWCNT; ZnO. In the second group, “techniques and characters”, the topics are: Electrospinning / Electrospun; Nanofibers / Nanofibrous; Nanoparticles / Nanorods / Quantum dots; Non-woven; Superhydrophobic / Superhydrophobicity.

Finally in the third group, “uses”, the topics are: Health and Medical uses ; Self-cleaning; Soldier / Battlewear / Military; UV / Ultraviolet / Ultraviolet-blocking / anti-UV / UV-blocking; Wearable.

For each of the three group a figure (figures 3, 4 and 4 respectively) presents the evolution of the fractions of the total number of scientific products in the year presented in table 4.

What is mostly relevant is the trend of each search term/group of search terms. In fact trends are not fully comparable due to the fact that some of them are the result of the sum of the results for several terms related among them (see for instance the terms for “Health and medical uses”) or referring to the same object (e.g. Carbon nanotube, CNR or MWCNT).

Trends start from 2002 as in the first two years the low total number of scientific products caused some bias in the percentages.

In the “materials” group it is possible to note the growth up to 2011 of works related to the use of Metals and metallic oxides; another metal oxide (ZnO, Zinc Oxide) has its own trend (slightly growing) due to the higher number of occurrences.

Also occurrences of (nano)Silver grows until 2011, while trends for Nanotubes and (nano)Composites are more stable.

The trend of (nano)Silver is also rather stable, and presents the highest absolute number of occurrences in the group.

In the "Techniques and characters" group the most visible trend is that of "Nanoparticles / Nanorods / Quantum dots" which again presents a peak in 2011. Nevertheless the trends of "Electrospinning / Electrospun" and "Nanofibers / Nanofibrous" are more stable with time (and present the highest numbers of occurrences).

Finally, in the "Uses" group the most evident trend is that of "Health and medical use". This is also due to the high number of search terms exploited to build the trend. Nevertheless what is most relevant is the fact that this trend is more or less continuously growing across time. Other trends are more stable, with the exclusion of "Wearable" which presents a steep maximum in the last year, 2014.

The obtained results described in the present section are the basis for the discussion presented in the fifth and last section.

DISCUSSION AND CONCLUSIONS

Aim of the present work is a preliminary analysis of the existing scientific literature on the topic of the applications of Nanosciences and Nanotechnologies to the production of textiles, fibres, fabrics and clothes. The study is relevant both due to the importance of the topic on the industrial and scientific side, and to the substantial lack of deepening on the specific topic. The analysis has been conducted on a dataset obtained with a specific methodology from the commercial web-based database Scopus®.

The first relevant fact is that, with respect to the total number of NST scientific products existing, the numbers of the present dataset are relatively scarce. This might be due either to the use of a conservative methodology, aiming at excluding spurious results, or to the fact that the topic encounters the interest of practitioners rather than that of researchers and scientists.

Under this point of view further studies are envisaged.

A second relevant fact is the evolution across the years of the number of scientific products encompassed in the database.

This in turn is a proxy for the interest of scientists in performing research activities in this specific field. Numbers show a more or less continuous growth from 2000 to 2008. After this year the number of scientific products witnesses a sudden decrease and a stabilization. The evolution of this trend is easily explainable if we think to an initial scenario of enthusiasm towards an unexplored scientific field. Then the enthusiasm presents a decrease and the research focuses only on some specific topics, more relevant either from the scientific or the technological/innovative point of view.

It is in fact possible to notice that in the years after 2008 some specific keywords (e.g. those related to metals and oxides, Nanoparticles, or also the ever-growing medical/health topics) present a peak of their presence in the titles of the scientific works.

This could mean that research has focused, after the first, "enthusiastic" years, on such more promising topics.

The analysis of citations is not able at this stage to offer indications on the relevance of the literature encompassed in the database; nevertheless the average number of citations present in some of the studied years is relatively high (see for instance the values of 2008 and 2010).

If we discuss the topics highlighted in the analysis of the titles of the scientific products in the database, it is important to recall those works presented in the literature overview. This is important also to find the connections existing between the different highlighted keywords. In fact if for instance we look at the “materials” keywords, we can look at the applications of those presented in our data. The most relevant application of Silver (usually applied in nanoparticles at the surface of the fibres) is as an antibacterial in medical/health applications, or for conferring anti-odour properties in sport and outdoor clothing. As the literature review shows, similar properties are conferred to clothes also using other metals or metal oxides having bactericide or catalytic properties. Metal oxides are used also to confer self-cleaning properties to textiles.

Coming to “Techniques and characters” Electrospinning is a relevant technique – as also shown by the number of publications – used to produce industrially nanofibers. This topic is also more or less continuously studied in literature. Using this technique is also possible to include in the fibres objects such as Carbon nanotubes, or the above discussed Nanoparticles, in order for instance to reinforce the same fibres or to confer electric properties (using Nanotubes).

These Nanocomposite materials are also continuously studied all over the timespan of the database. Also Nanoparticles are a relevant topic across time, and it is important to note that the peak in their graph coincides with the peak of the “Metals and oxides” and of the “(nano)Silver” trends. This might indicate a compresence in the same works: the importance of metal and oxide nanoparticles has been introduced above.

Finally, the importance of the NST applications in the of textiles for health and medical uses has been widely discussed above. This is also the topic that –more than other ones – shows a more or less growing path all along the timespan of the database. This in probably due to both the relevance of the topic and its importance in terms of technologies to develop, possible innovation and consequent economic impact.

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APPENDIX

Table 1 – Number of scientific products per year of publication

YEAR	**SCIENTIFIC PRODUCTS**
2000	3
2001	11
2002	16
2003	29
2004	48
2005	69
2006	70
2007	73
2008	89
2009	63
2010	53
2011	58
2012	58
2013	54
2014	30
TOTAL	**739**

Table 2 – Number of average received citations per year and of average received citations per paper per year.

YEAR	**CITATIONS/PAPER/YEAR**
2000	0.563
2001	0.539
2002	1.161
2003	2.668
2004	1.644
2005	1.659
2006	1.104
2007	2.033
2008	3.815
2009	1.147
2010	6.547
2011	2.000
2012	1.625
2013	1.105
2014	1.417
TOTAL	**2.174**

Table 3 – Most relevant words in titles: number of occurrences per year

Words	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	TOTAL
(nano)Composites	0	1	0	2	0	1	2	1	6	6	7	6	1	3	1	**37**
(nano)Silver	0	1	0	0	0	1	5	4	8	5	5	8	6	2	3	**48**
Metals and oxides (Al2O3/SiO2/TiO2/MgO/Copper/Gold/Palladium/Nickel)	0	0	0	0	1	1	2	2	8	5	5	11	5	4	0	**44**
Nanotube/CNT/MWCNT	0	1	0	0	2	2	1	0	8	2	3	5	1	0	2	**27**
ZnO	0	0	0	0	0	0	1	1	1	2	1	2	3	0	2	**13**
Electrospinning/Electrospun	0	2	0	3	3	5	2	8	14	8	4	3	3	4	2	**61**
Nanofibers/Nanofibrous	0	3	2	4	3	6	3	0	11	9	1	6	6	5	3	**62**
Nanoparticles/Nanorods/Quantum dots	0	0	0	2	0	0	3	5	11	5	5	14	6	3	3	**57**
Non-woven	0	0	0	1	2	4	3	0	2	7	1	0	0	0	1	**21**
Superhydrophobic/Superhydrophobicity	0	0	0	0	0	0	0	1	1	0	2	0	2	2	2	**10**
Health and Medical use	0	0	1	5	4	11	7	10	12	9	7	13	18	12	8	**117**
Self-cleaning	0	0	0	0	0	1	0	1	1	0	1	1	1	3	0	**9**
Soldier/Battlewear/Military	0	0	0	1	2	1	0	1	2	0	0	0	1	0	0	**8**
UV/Ultraviolet/ultraviolet-blocking/anti-UV/UV-blocking	0	0	0	1	1	0	3	4	2	2	0	2	1	3	0	**19**
Wearable	0	0	0	0	0	1	0	0	3	1	0	1	2	1	4	**13**

Table 4 – Most relevant words in titles: fraction of scientific products containing the word over the total scientific products of the year

Words	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
(nano)Composites	0.00	9.09	0.00	6.90	0.00	1.45	2.86	1.37	6.74	9.52	13.21	10.34	1.72	5.56	3.33
(nano)Silver	0.00	9.09	0.00	0.00	0.00	1.45	7.14	5.48	8.99	7.94	9.43	13.79	10.34	3.70	10.00
Metals and oxides (Al2O3/SiO2/TiO2/MgO/Copper/Gold/Palladium/Nickel)	0.00	0.00	0.00	0.00	2.08	1.45	2.86	2.74	8.99	7.94	9.43	18.97	8.62	7.41	0.00
Nanotube/CNT/MWCNT	0.00	9.09	0.00	0.00	4.17	2.90	1.43	0.00	8.99	3.17	5.66	8.62	1.72	0.00	6.67
ZnO	0.00	0.00	0.00	0.00	0.00	0.00	1.43	1.37	1.12	3.17	1.89	3.45	5.17	0.00	6.67
Electrospinning/Electrospun	0.00	18.18	0.00	10.34	6.25	7.25	2.86	10.96	15.73	12.70	7.55	5.17	5.17	7.41	6.67
Nanofibers/Nanofibrous	0.00	27.27	12.50	13.79	6.25	8.70	4.29	0.00	12.36	14.29	1.89	10.34	10.34	9.26	10.00
Nanoparticles/Nanorods/Quantum dots	0.00	0.00	0.00	6.90	0.00	0.00	4.29	6.85	12.36	7.94	9.43	24.14	10.34	5.56	10.00
Non-woven	0.00	0.00	0.00	3.45	4.17	5.80	4.29	0.00	2.25	11.11	1.89	0.00	0.00	0.00	3.33
Superhydrophobic/Superhydrophobicity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.37	1.12	0.00	3.77	0.00	3.45	3.70	6.67
Health and Medical use	0.00	0.00	6.25	17.24	8.33	15.94	10.00	13.70	13.48	14.29	13.21	22.41	31.03	22.22	26.67
Self-cleaning	0.00	0.00	0.00	0.00	0.00	1.45	0.00	1.37	1.12	0.00	1.89	1.72	1.72	5.56	0.00
Soldier/Battlewear/Military	0.00	0.00	0.00	3.45	4.17	1.45	0.00	1.37	2.25	0.00	0.00	0.00	1.72	0.00	0.00
UV/Ultraviolet/ultraviolet-blocking/anti-UV/UV-blocking	0.00	0.00	0.00	3.45	2.08	0.00	4.29	5.48	2.25	3.17	0.00	3.45	1.72	5.56	0.00
Wearable	0.00	0.00	0.00	0.00	0.00	1.45	0.00	0.00	3.37	1.59	0.00	1.72	3.45	1.85	13.33

Figure 1 – Number of scientific products per year of publication.

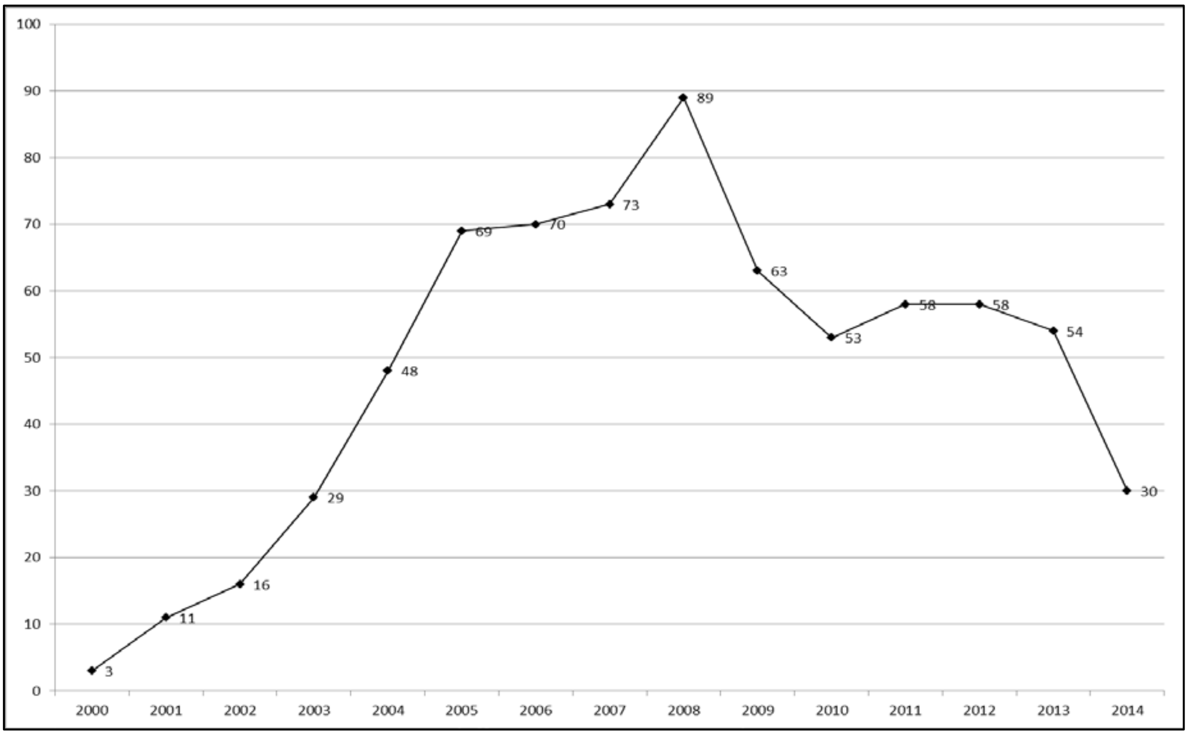

Figure 2 – Number of average received citations per paper per year.

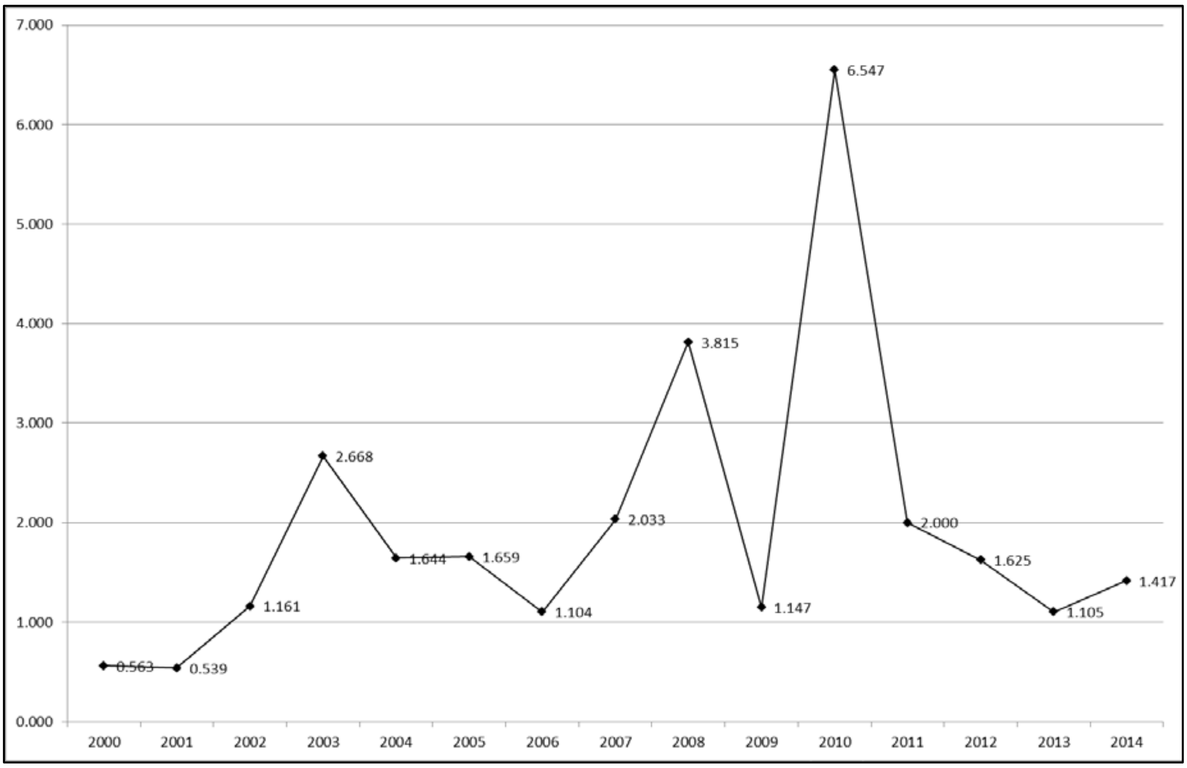

Figure 3 – Most relevant words in titles: fraction of scientific products containing the word over the total scientific products of the year: materials

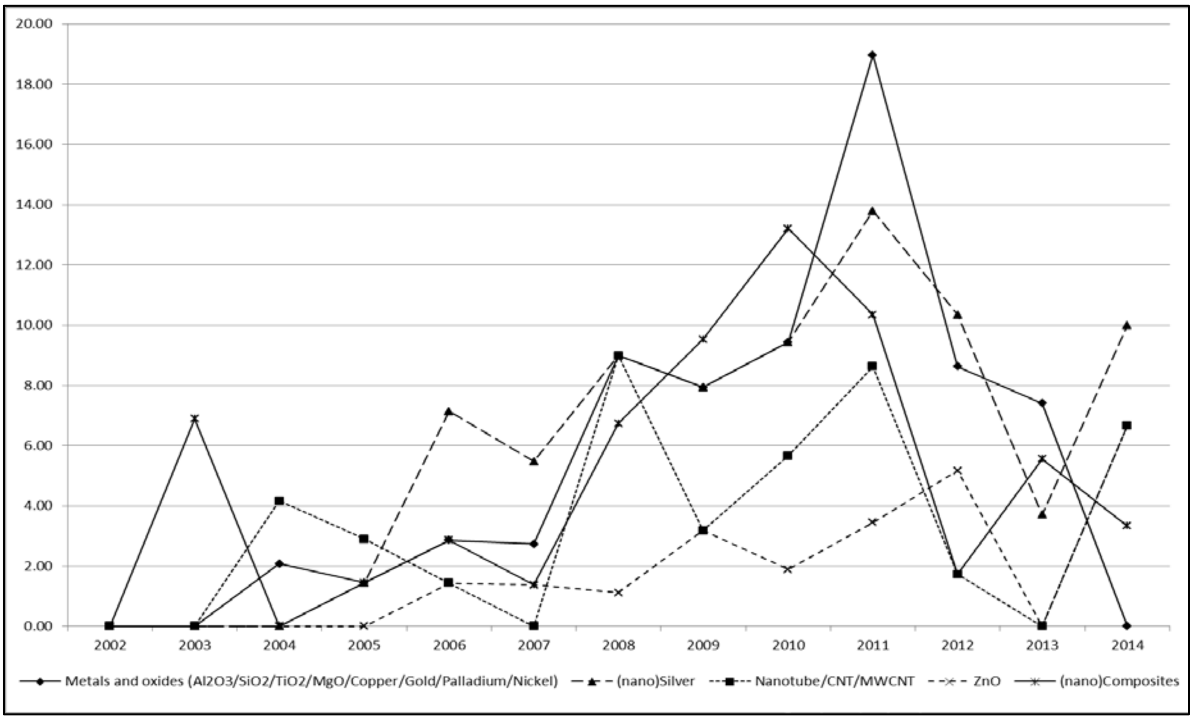

Figure 4 – Most relevant words in titles: fraction of scientific products containing the word over the total scientific products of the year: techniques and characters

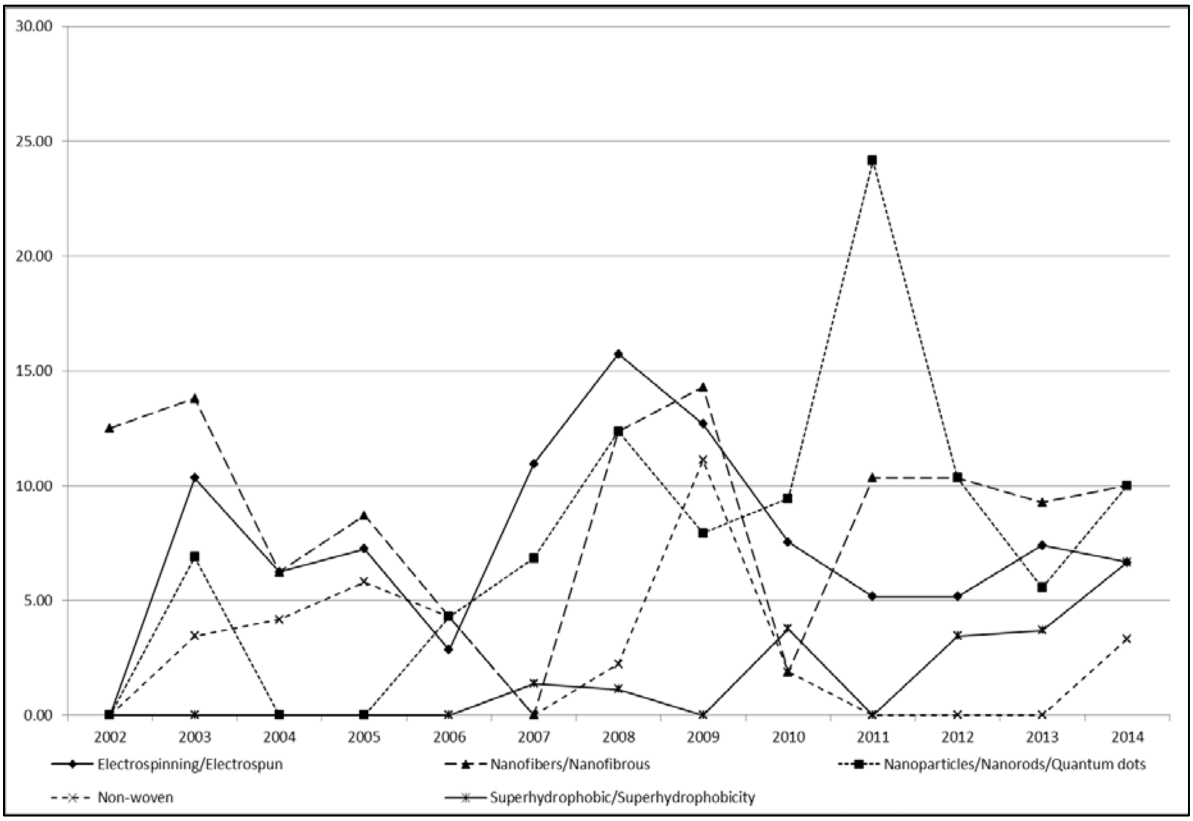

Figure 5 – Most relevant words in titles: fraction of scientific products containing the word over the total scientific products of the year: uses