J Nanopart Res (2009) 11:1883–1893
DOI 10.1007/s11051-009-9765-0

RESEARCH PAPER

Impact and structure of literature on nanoparticle generation by laser ablation in liquids

Stephan Barcikowski · Francisco Devesa · Kirsten Moldenhauer

Received: 4 August 2009 / Accepted: 15 September 2009 / Published online: 27 September 2009

Abstract The number of publications on laser ablation and nanoparticle generation in liquids increased by the factor of 15 in the last decade, with comparable high impact of the most cited articles in this field. A nearly unlimited variety of nanoparticle material, liquid matrix, and conjugative agent can be combined to a huge variety of colloids within a few minutes of laser processing. However, this diversification makes it hard to identify main research directions without a comprehensive literature overview. This investigation evaluates the impact and structure of the literature in this field tagging most prolific subjects and articles. Using an optimized search algorithm, the data sets derived from Science Citation Index (1998–2008) allow for statements on publication subject clusters, impact of articles and journals, as well as mapping global spots of activities.

Keywords Bibliometric analysis · Literature · Nanoparticle · Laser ablation · Colloid · Nanomaterial · Nanomanufacturing

S. Barcikowski (✉) · F. Devesa · K. Moldenhauer
Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany
e-mail: s.barcikowski@lzh.de
URL: http://www.lzh.de

S. Barcikowski
Excellence Cluster REBIRTH, Hollerithallee 8, 30419 Hannover, Germany

Introduction

The nanotechnology literature pool has been growing fast. For example, 56,000 nano research articles were recorded by the Web of Science (WOS) in 2006 (Porter et al. 2008), and 65,000 records of instrumentation literature associated with nanoscience or nanotechnology were retrieved from the Science Citation Index for 2005 (Kostoff et al. 2007). The ten most cited references in this field acquire from a few hundred citations per year up to a total of several thousand citations (Kostoff et al. 2006). However, taking these top ten nanotechnology articles as example, they span topics from carbon nanotubes to self-assembly methods or nanolasers. Consequently, it may be difficult for a nanotechnology researcher who is active in a particular nanotechnology subject to derive information on the literature infrastructure in his/her field and to weight the impact of his/her study relative to the overall development of his/her community. Moreover, for young researchers, it may be important to indentify main research directions, most active countries, and major players in their focused field.

In this context, laser fabrication of nanoparticles in liquids is a relatively young but growing research field. Today, nanoparticles are widely implemented as functional elements in plastics, lacquers, and ceramic products. Novel applications are targeted on nanomedicine, sensing, electronics, optics, and biophotonics. However, only a limited variety of nanomaterials that may be integrated into advanced functional materials are available. Nanoparticles synthesized by conventional gas phase processes are often agglomerated to micro powders that are hardly redispersible into functional matrices like polymers. Conventionally, the generation of colloidal nanoparticles is well established by chemical synthesis methods. However, application prospects might be restricted due to possible impurities resulting from the use of surfactants, chemical precursors, or reducing agents (Dahl et al. 2007). Laser ablation in liquids starts to overcome these agglomeration and impurity problems, since this method leads to *charged nanoparticles* (Sylvestre et al. 2004a, b) zeta potential of which results in high colloidal stability and does *not require chemical precursors,* and thus purification steps are obsolete (Dahl et al. 2007). It can be applied universally with an almost unlimited variety of nanomaterials and liquid matrices, and creates colloids which are not inhalable similar to powders and, thus, lead to an improved situation with respect to occupational safety.

Not only fundamentals behind laser ablation in liquids have recently been discussed in literature, but also the design of nanohybrids such as nanoparticle–polymer composites (Compagnini et al. 2002; Barcikowski et al. 2008; Hahn and Barcikowski 2009) and bioconjugated nanoparticles (Petersen and Barcikowski 2009) via laser ablation. This is quite remarkable for such a young technology, which was established only in the early 1990s (Fojtik and Henglein 1993). In the last decade, laser ablation in liquids has proven to be a unique and efficient technique to generate, fragmentate, re-shape, and conjugate nanoparticles. Today, prospects of applications may be enabled by laser ablation in liquids, especially since it has recently been demonstrated that this method has entered the gram scale (Sattari et al. 2008).

A nearly unlimited variety in

(a) nanoparticle material: metals (Tsuji et al. 2002; Barcikowski et al. 2007), alloys (Hodak et al. 2000; Voronov et al. 2004; Abdelsayed et al. 2008), ceramics (Wang et al. 2003) or semiconductors (Zeng et al. 2005) and organic material (Asahi et al. 2008),
(b) liquid matrix: water (Mafune et al. 2002), organic solvents (Compagnini et al. 2003; Hahn and Barcikowski 2009), ionic liquids (Kimura et al. 2007), and
(c) conjugative agent: biomolecules (Sylvestre et al. 2004a, b; Petersen and Barcikowski 2009), polymers (Besner et al. 2009; Barcikowski et al. 2008), surfactant (Mafune et al. 2002; Usui et al. 2005; Hahn et al. 2008)

leads to a nearly unlimited variety of colloids and nanomaterials that can be designed within a few minutes of laser processing. However, exactly, this wide aspect is represented in a huge variety in scientific publications in that field, which makes it hard to find main research directions. An evaluation of the impact and structure of the literature in this field may help researchers to orientate and locate themselves in their scientific community.

Approach and bibliometric method

The bibliometric method may be different, depending on whether a research topic and its technical methods are sharply focused or are more similar to a platform technology. Nanotechnology methods with sharp focus and a high number of publications, e.g., nanostructuring of silicone, allow for refinement of search terms using sharp terminology. The search then results in a pool of publications that makes statistical processing possible. Since the data set will then consist of several thousand entries, a few publications that may be out of scope will not affect the statements drawn from the bibliometric analysis. On the contrary, a platform technology such as laser ablation in liquids, owing to a limited number of publications, makes it possible to compare results from search term refinement using Boolean operators and manual selection of a pool based on a few keywords. In this way, the Boolean term may be optimized by the feedback of the reading of the abstracts within the record. This feedback approach aims at a refined query adapted to the scientific community of laser fabrication of nanoparticles in liquids.

Initial data set generation

In a first approach, different search queries for the Web of Sciences' Science Citation Index (SCI) were generated since November 2008. To that end, title-search (ts) queries probing subsets of the literature pool of nanoparticles, laser materials processing, as

Table 1 SCI Database query

Search set	Search string	SCI results
	"nanoparticles"	as of 3/25/09
#1	(nanoparticle* OR nanocrystal* OR nanowire* OR nanotub* OR nanofibre* OR nanofiber* OR nanosphere* OR nanorod* OR nanodot* OR quantum dot* OR quantum wire*)	185,065
	"laser materials processing"	as of 3/25/09
#1	laser*	
#2	(ablation OR cutting OR welding OR cladding OR sintering OR processing OR structuring OR marking OR soldering)	
#3	#1 AND #2	28,705
	"laser-nanoparticles"	as of 3/25/09
#1	laser*	
#2	(generation OR generated OR generating OR fragmentation OR fragmentated OR fragmentating OR fabrication OR fabricated OR fabricating OR fragmentation OR fragmentated OR fragmenting OR ablation OR ablated OR ablating OR production OR produced OR producing)	
#3	(nanoparticle* OR nanocluster* OR nanocrystal* OR nano-sphere* OR nanosphere*)	
#4	(liquid* OR water OR solvent* OR colloid* OR hydrosol* OR hydro-sol* OR alkan* OR solution* OR propanol OR dispers* OR suspens* OR aqueous)	
#5	#1 AND #2 AND #3 AND #4	1,200

well as laser generation of nanoparticles in liquids were combined by Boolean operators. Results were restricted to the time period from 1998 to 2008. The queries yielded initial data sets of around 1,200–1,800 records. The most representative examples of these queries are given in Table 1, together with the number of hits as of 3/25/09.

The initial data sets contained a high number of publications that were out of scope since the overlap of the resulting nanoparticles and laser materials processing records is bigger than the considered research field. However, the pool of articles on laser fabrication and melting/fragmentation of nanoparticles in liquids should be included as a subset in this data set and can be extracted by manual examination of the query results.

Data set refinement

The initial data set records were inspected by reading the abstracts. In only a few cases, the full article had to be examined where the abstract was too short or not clear. Two subject groups were identified that were out of scope. First, the data set contains numerous publications on pulsed laser deposition (PLD) technique. Since PLD results in immobilized particles and nanostructured surfaces are more likely than in colloidal nanoparticles or volume-dispersed nanocomposites, these articles had to be sorted out. Second, a group of records in this set dealt with optical properties of nanoparticles, where the laser was used for laser illumination or spectroscopy and not for fabrication, shaping, melting, or fragmentation of the nanoparticles. Synthesis of colloids is an important topic since decades. Hence, focusing on colloids fabricated and fragmented using lasers, a NOT-coupled search string was introduced (Table 2, #6) to exclude articles on laser deposition, surface patterning, and non-liquid methods. Using the database query described in Table 2, 345 publications are recorded. Even if this search string gives a well-focused set of publications, a final inspection had to be done filtering out another 10%. Examples are Morales and Lieber (1998), which contained the keyword "liquid" in the abstract, although it reports a vapor deposition technique, or Pavesi et al. (2000), who report on silicon nanocrystals for semiconductor laser. Finally, 313 records were selected from the inspected publications which form the data set that our impact and structure analysis is based on. As out

Table 2 Improved SCI database query

Search set	Search string	SCI results
	"laser-nanoparticles (refined)"	as of 4/30/09
#1	laser*	
#2	(generation OR generated OR generating OR fragmentation OR fragmentated OR fragmentating OR fabrication OR fabricated OR fabricating OR fragmentation OR fragmentated OR fragmenting OR ablation OR ablated OR ablating OR production OR produced OR producing)	
#3	(nanoparticle* OR nanocluster* OR nanocrystal* OR nanosphere* OR nanosphere)	
#4	(liquid* OR water OR solvent* OR colloid* OR hydrosol* OR hydro-sol* OR alkan* OR solution* OR propanol OR dispers* OR suspens* OR aqueous)	
#5	#1 AND #2 AND #3 AND #4	1,200
#6	(gas phase* OR vacuum OR deposition OR pld OR surface OR structure* OR laser spectroscopy)	
#7	#5 NOT #6	345

of scope fields could be identified, the initial search query could be adapted to better match our manually selected "laser-nanoparticles (refined)" data set. Table 2 shows the improved database query. The resulting data set, of course, is not identical to the manually filtered data set, but reflects it much better in terms of the number of results and the articles contained. For example, all of the most cited articles shown in Table 3 are contained in both data sets.

This database query can serve as a tool for researches in this community to periodically update their literature database on laser ablation and nanoparticle generation in liquids and should require only minimal effort of manual filtering.

Since researchers are being active in both, the wider "laser-nanoparticles" and the colloid-focused "laser-nanoparticles (refined)" fields, both data sets are analyzed in the following. The first might be interesting for senior researchers seeking a broader view, whereas the latter might be useful for scientists focusing on laser-assisted colloid synthesis.

Results

Publication activity trend

The scientific field laser generation of nanoparticles in liquids may be regarded as an intersection between the scientific communities of laser materials processing and nanoparticles research. In Fig. 1, we have compared the publication activity in these two fields and its intersection. It can be clearly seen that the growth rate of laser materials processing publications is far lower than the increase in number of nanoparticles publications. In 1998, the publication activity in both fields "laser materials processing" and "nanoparticles" was in the same order of magnitude (2,000 and 4,750 research articles per year). A decade later, in 2008, nanoparticles articles (35,560 per year) are more than ten times higher in number than publications on laser materials processing (3,120 per year). This growth rate of nanoparticles literature is even higher than the overall nanoscience and nanotechnology publication activity trend. According to Kostoff et al. (2006), the search term used for the bibliometric analysis of the nanoparticles field is a part of the nanoscience and nanotechnology search term, and so it may be assumed that research interest in nanoparticles strongly determine the global nanotechnology literature statistics.

While comparing the trends with the data set from the topic laser generation of nanoparticles in liquid "laser-nanoparticles," it can be seen that the growth in publications is more likely according to the trend on nanoparticle research than on laser materials processing. Today, around 100 articles are published per year on this topic. In the last decade, the number of publications in this field grew by a factor of 15.

Table 3 Most cited articles and journals of the "laser-nanoparticles (refined)" data set

Author	Journal	Year	Vol/iss	Page	Cit./year	Citations
Link, S; El-Sayed, MA	*J. Phys. Chem. B*	1999	103/40	8410	99	887
Spectral properties and relaxation dynamics of surface plasmon electronic oscillations in gold and silver nanodots and nanorods						
Kamat, PV; Flumiani, M; Hartland, GV	*J. Phys. Chem. B*	1998	102/17	3123	26	257
Picosecond dynamics of silver nanoclusters. Photoejection of electrons and fragmentation						
Hodak, JH; Henglein, A; Giersig, M; et al.	*J. Phys. Chem. B*	2000	104/49	11708	17	133
Laser-induced inter-diffusion in AuAg core–shell nanoparticles						
Link, S; Burda, C; Mohamed, MB; et al.	*J. Phys. Chem. A*	1999	103/9	1165	14	127
Laser photothermal melting and fragmentation of gold nanorods: Energy and laser pulse-width dependence						
Fujiwara, H; Yanagida, S; Kamat, PV	*J. Phys. Chem. B*	1999	103/14	2589	12	105
Visible laser induced fusion and fragmentation of thionicotinamide-capped gold nanoparticles						
Link, S; Wang, ZL; El-Sayed, MA	*J. Phys. Chem. B*	2000	104/33	7867	11	85
How does a gold nanorod melt?						
Simakin, AV; Voronov, VV; Shafeev, GA; et al.	*Chem. Phys. Lett.*	2001	348/3–4	182	12	83
Nanodisks of Au and Ag produced by laser ablation in liquid environment						
Tsuji, T; Iryo, K; Watanabe, N; et al.	*Appl. Surf. Sci.*	2002	202/1–2	80	12	71
Preparation of silver nanoparticles by laser ablation in solution: Influence of laser wavelength on particle size						
Kabashin, AV; Meunier, M; Kingston, C; et al.	*J. Phys. Chem. B*	2003	107/19	4527	14	68
Fabrication and characterization of gold nanoparticles by femtosecond laser ablation in an aqueous solution of cyclodextrins						
Eliezer, S; Eliaz, N; Grossman, E; et al.	*Phys. Rev. B.*	2004	69/14		17	66
Synthesis of nanoparticles with femtosecond laser pulses						
Kabashin, AV; Meunier, M	*J. Appl. Phys.*	2003	94/12	7941	12	58
Synthesis of colloidal nanoparticles during femtosecond laser ablation of gold in water						
Chandrasekharan, N; Kamat, PV; Hu, JQ; et al.	*J. Phys. Chem. B*	2000	104/47	11103	7	55
Dye-capped gold nanoclusters: Photoinduced morphological changes in gold/rhodamine 6G nanoassemblies						
Usui, H; Shimizu, Y; Sasaki, T; et al.	*J. Phys. Chem. B*	2005	109/1	120	18	53
Photoluminescence of ZnO nanoparticles prepared by laser ablation in different surfactant solutions						
Hayakawa, K; Yoshimura, T; Esumi, K	*Langmuir*	2003	19/13	5517	10	50
Preparation of gold-dendrimer nanocomposites by laser irradiation and their catalytic reduction of 4-nitrophenol						
Sylvestre, JP; Poulin, S; Kabashin, AV; et al.	*J. Phys. Chem. B*	2004	108/43	16864	12	49
Surface chemistry of gold nanoparticles produced by laser ablation in aqueous media						
Link, S; El-Sayed, MA	*J. Chem. Phys.*	2001	114/5	2362	7	48
Spectroscopic determination of the melting energy of a gold nanorod						
Mafune, F; Kohno, JY; Takeda, Y; et al.	*J. Phys. Chem. B*	2002	106/34	8555	8	46
Growth of gold clusters into nanoparticles in a solution following laser-induced fragmentation						
Zeng, HB; Cai, WP; Li, Y; et al.	*J. Phys. Chem. B*	2005	109/39	19260	13	40
Composition/structural evolution and optical properties of ZnO/Zn nanoparticles by laser ablation in liquid media						
Ganeev, RA; Baba, M; Ryasnyansky, AI; et al.	*Opt. Commun.*	2004	204/4–6	437	10	38
Characterization of optical and nonlinear optical properties of silver nanoparticles prepared by laser ablation in various liquids						
Compagnini, G; Scalisi, AA; Puglisi, O	*Phys. Chem. Chem. Phys.*	2002	4/12	2787	6	36
Ablation of noble metals in liquids: a method to obtain nanoparticles in a thin polymeric film						

Subject areas and clusters

In addition to the comparison of the publication activity of a topic (laser-nanoparticles) with the broader field (e.g., nanoparticles or laser), the respective data set can be analyzed intrinsically by the subject area groups according to the SCI subject categories. Figure 2 ranks these subject categories of

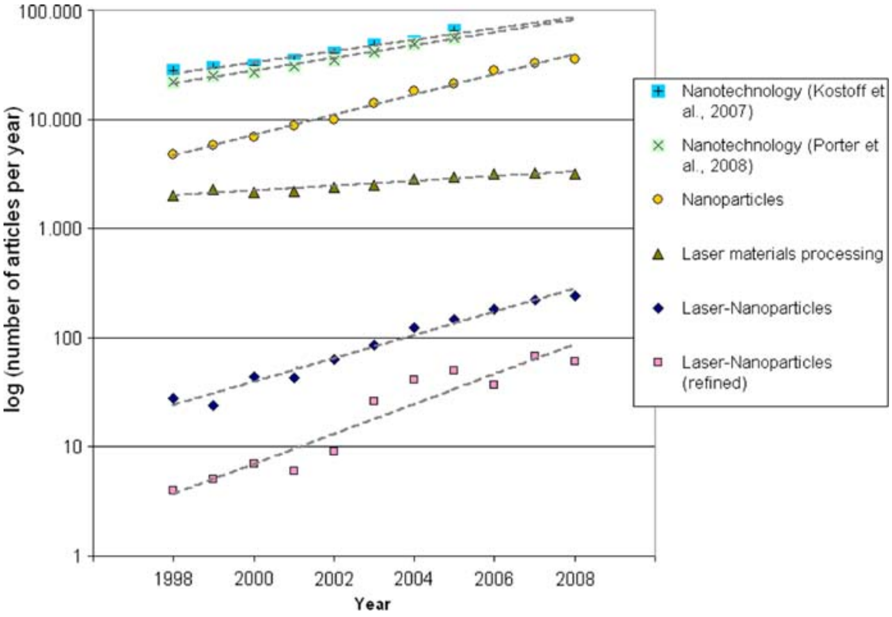

Fig. 1 Number of research publications per year within the last decade in the fields of nanoscience/nanotechnology, nanoparticles, laser materials processing, and laser generation of nanoparticles

scientific publications (1998–2008) in the field of laser ablation and generation of nanoparticles in liquids. Natural science is the dominant discipline, with the subject areas physical chemistry, applied physics, and materials science having the highest (two-digit) share of overall publications.

Clusters are identified from the SCI subject categories (Fig. 2) and displayed in Fig. 3. Independent from the search string used, chemistry (including materials science) is the most frequent category within the data set "laser-nanoparticles." This observation fits to the findings from Fig. 1, where a relation to nanoparticles publication activity was identified, since research on "nanoparticles" traditionally is a research subject of physical chemistry since decades (Faraday 1857).

Interestingly, the life science subject cluster (biology, medicine) only plays a minor role. This is notable because authors in the field of laser ablation and generation of nanoparticles in liquids often claim the high purity of the colloids fabricated by this method referring to prospective applications in life sciences such as biosensing (Sylvestre et al. 2004a, b; Besner et al. 2009) or drug delivery and nanomarkers

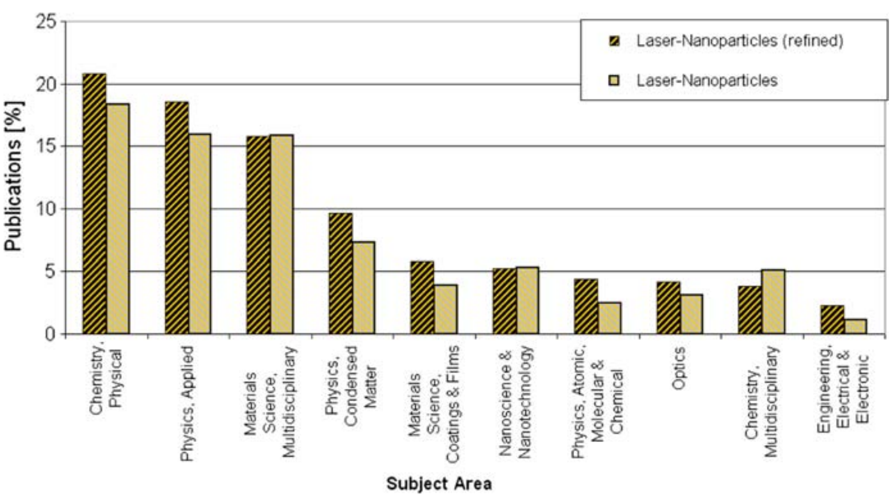

Fig. 2 Subject categories by SCI classification of scientific publications in the last decade in the field of laser ablation and generation of nanoparticles in liquids

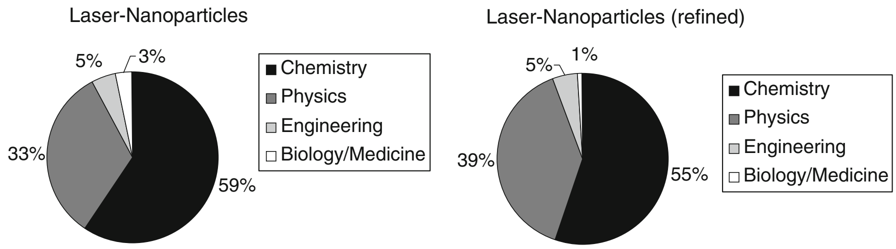

Fig. 3 Subject clusters of scientific publications in the last decade in the field of laser ablation and generation of nanoparticles in liquids

(Petersen and Barcikowski 2009). Analysis of nanotechnology publications by a bibliometric project addressing creative research in the domains of nanotechnology and human genetics revealed a comparable high share of 38% of publications with bio-oriented terms of total nanotechnology publications (Heinze et al. 2007). A follow-up study (Porter et al. 2008) was aiming to narrow the degree in which basic biological research is manifested in the nanotechnology publication profile. This study revealed still 12% articles with bio-oriented search terms within total nanotechnology publications. On the contrary, the subject cluster analysis of publications on colloids fabricated by laser ablation (Fig. 3) shows that only 1–3% of the results are bio-focused. The laser-based nanomanufacturing method is comparatively young and has just started to demonstrate first applications, so that it may be expected that this gap between the noteworthy bio-orientation of overall nanotechnology and nanoparticle publications and the comparatively young laser-nanoparticles field may be narrowed in future.

Most cited articles and journals

The Science Citation Index helps estimating the impact of both, individual research articles and scientific journals. In addition, it gives a first guess of the research focus and leaders in the main stream of the respective topic. The ten most cited references in the field of nanoscience and nanotechnology were cited 500–4,100 times in total with 200–700 citations in the year 2003 (Kostoff et al. 2006). A lower impact of articles in the topic “laser-nanoparticles” would be expected for this focused research field with only 25 (refined SCI data set) or 85 (SCI) articles in 2003. In Table 3, the 20 most cited articles and journals from the refined data set are listed. The list of most cited articles from this community contains well-recognized publications (up to 887 total citations or 99 citations per year). This is surprising, taking into account that the overall number of publications in this field is two orders of magnitude lower compared to total nanotechnology or nanoparticles publications. The addressed topic is obviously recognized by a wider scientific community.

The top-20 list of publications on laser ablation in liquids contains two main subject clusters: laser fragmentation of colloidal nanoparticles and laser fabrication of nanoparticles. The laser fragmentation (or post-irradiation) subject cluster fills the highest ranks (Link and El-Sayed 1999; Kamat et al. 1998; Hodak et al. 2000). This cluster is of higher impact probably because spectral properties of laser-fragmented and molten nanoparticles or laser photochemistry are of interest for a wider community. The second subject cluster of the top-20 “laser-nanoparticles” publication list focuses on laser fabrication of colloidal nanoparticles. The first ranks in this subgroup are placed by Russian (Simakin et al. 2001), Japanese (Tsuji et al. 2002), and Canadian (Kabashin et al. 2003) authors.

It has to be considered that some articles in this list were published only 3–4 years ago (e.g., Usui et al. 2005 with already 18 citations per year), so that the ranking can only help to roughly estimate the topics recognized by other researchers. Contrary to the ranking of individual articles, the identification of the most prolific journals in this field is quite clear. J. Phys. Chem. B is the most prolific journal in this field. This is in accordance with the findings from the subject cluster analysis (Figs. 2, 3), where the subject “physical chemistry” (Fig. 2) or the clusters “chemistry” and “physics” (Fig. 3) are the most dominant areas.

Most prolific countries

The most active countries and regions in the field “laser-nanoparticles” may be identified by the

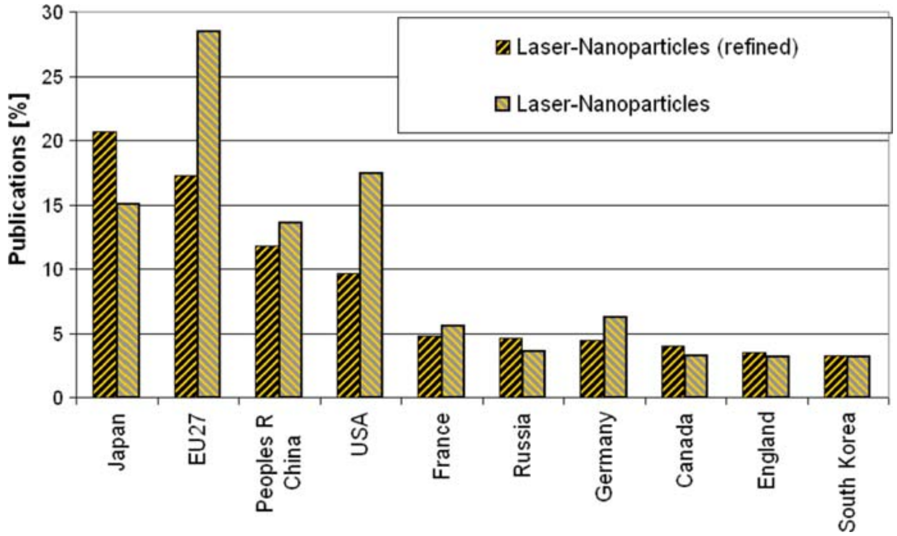

Fig. 4 Share of global scientific publication activity (1998–2008) by country in the field of laser ablation and generation of nanoparticles in liquids

analysis of the author's affiliations given in the scientific articles. Figure 4 shows the global scientific publication activity (1998–2008) by country in the field of laser ablation and generation of nanoparticles in liquids. EU27 and USA have a higher share of publication in the laser-nanoparticles record compared to the refined data set. This might be due to their stronger research activity in laser deposition and nanostructuring, fields which are excluded in the refined search string focusing on publications addressing colloids. In both data sets, Japan, China, and USA are the states with the highest number of publications and a double-digit ratio (Fig. 4).

Japan is the most prolific country in the refined SCI record. This is different compared to the broader data of total nanoscience and nanotechnology articles (Kostoff et al. 2006), where the ranking was USA (8,037 articles), China (5,644 articles), and Japan (4,617 articles). In addition, Russia, France, and Canada are more active in the "laser-nanoparticles" field compared to their total publication activity in nanoscience and nanotechnology. The publication activity of the leaders of the cumulative ranking in Fig. 4 is studied in detail with respect to their annual share in Fig. 5. No clear trend can be seen probably because, on the one hand, the data set is too small to detect national activity trends. On the other hand, transnational publications may give crosslinks within this statistics, linking one national activity growth to the other. This crosslinking is supported by the observation that the "laser-nanoparticles (refined)" record contains a share of 18% transnational co-authored publications. Among these, USA (18), France (17), and Japan (16) have the highest share of transnational articles, followed by Russia (12) and Germany (11).

Global activities and regional clusters

The bibliometric analysis of the most prolific countries (Fig. 4) indicates that clusters of global "laser-nanoparticles" publication activities are expected to be located in Asia, North America, and Europe. In order to spot these transnational geographic clusters, the global locations of 553 author and co-author institutions of the refined SCI data set were mapped at 111 spots or metropolitan areas. Figure 6 shows that, in fact, it is an international community with three main regional clusters: (1) not only all over Japan, but also South Corea, and East China; (2) Western Europe; (3) east coast of USA and Canada.

Summary and conclusion

The number of publications of laser ablation and nanoparticles generation in liquids is growing fast, with an average yearly increase of 150% in the last decade. Literature data analysis shows that this growth is linked to nanoparticles research more likely than research on laser materials processing. The refinement of the search strategy enables the

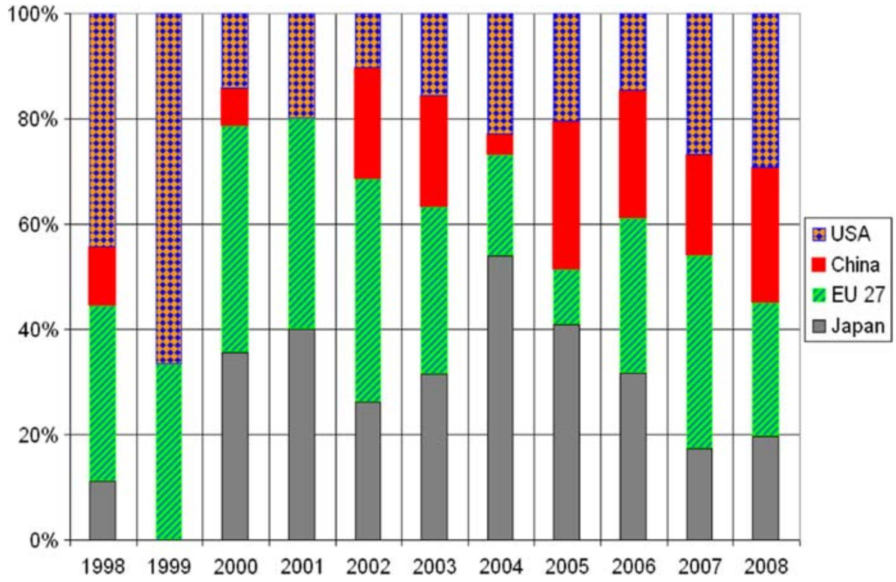

Fig. 5 Share of scientific publication activity levels (1998–2008) in the field of laser ablation and generation of nanoparticles in liquids

Fig. 6 Global spots of publication activity (author's and co-author's affiliations in publications 1998–2008). Identification of geographic clusters on laser-nanoparticles research

differentiation of the literature data set on this topic from a wider data pool including laser illumination and pulsed laser ablation in gas phase or vacuum. The refined search string may be used as a tool for researches in this community to periodically update their literature database.

Using this data set, the results of the Science Citation Index query for 1998–2008 allows for statements on publication subject clusters, impact of articles and journals, as well as mapping of global spots of activities.

Japan, China, and USA are the most active countries with a double-digit ratio, which is different compared to total nanoscience and nanotechnology with the ranking: USA, China, and Japan. The map of the article authors addressing laser ablation and nanoparticles generation in liquids implicates three regional clusters: (1) Japan, South Corea, and China; (2) Western Europe, and (3) East Coast of USA and Canada. Among co-authoring articles, a share of 18% transnational publications is recorded, stating that this discipline is globally networking.

The most cited articles address two topic clusters: laser excitation and laser fabrication of colloidal nanoparticles. Statistically, physical chemistry is the most important subject area, and chemistry, including materials science, the most important cluster of subjects in the "laser-nanoparticles" literature. This observation corroborates the results of the journal's impact data analysis within the top-20 articles, where journals from physical chemistry or chemical physics are consistently dominant.

Contrary to the broader nanotechnology publication profile, bio-oriented subjects are not significant, neither in the total "laser-nanoparticles" data set, nor in the most cited articles. In comparison to total nanotechnology articles where nano-bioresearch plays an important role in literature, here, bio-oriented subjects are not significant yet. Taking into account that the high impact research articles in the "laser-nanoparticles" field address mainly gold nanoparticles and nanorods, both widely used as nanomarkers in biomedicine and that since the last 2 years, first articles on laser-generated nano-biomaterials were published, a higher share of bio-oriented literature may be expected in this discipline in future.

Acknowledgment The authors thank the Deutsche Forschungsgemeinschaft for funding literature research within the projects BA 3580/2-1 and CH-179/9-1.

References

Abdelsayed V, Glaspell G, Nguyen M, Howe JM, El-Shall MS (2008) Laser synthesis of bimetallic nanoalloys in the vapor and liquid phases and the magnetic properties of PdM and PtM nanoparticles (M = Fe, Co and Ni). Faraday Discuss 138:163–180

Asahi T, Sugiyama T, Masuhara H (2008) Laser fabrication and spectroscopy of organic nanoparticles. Acc Chem Res 41:1790–1798

Barcikowski S, Hahn A, Kabashin AV, Chichkov BN (2007) Properties of nanoparticles generated during femtosecond laser machining in air and water. Appl Phys A 87:47–55

Barcikowski S, Hustedt M, Chichkov B (2008) Nanocomposite manufacturing using ultrashort-pulsed laser ablation in solvents and monomers. Polimery 53:657–662

Besner S, Kabashin AV, Winnik FM, Meunier M (2009) Synthesis of size-tunable polymer-protected gold nanoparticles by femtosecond laser-based ablation and seed growth. J Phys Chem C 113:9526–9531

Compagnini G, Scalisi AA, Puglisi O (2002) Ablation of noble metals in liquids: a method to obtain nanoparticles in a thin polymeric film. Phys Chem Chem Phys 4:2787–2791

Compagnini G, Scalisi AA, Puglisi O (2003) Production of gold nanoparticles by laser ablation in liquid alkanes. J Appl Phys 94:7874–7877

Dahl JA, Maddux BL, Hutchison JE (2007) Toward greener nanosynthesis. Chem Rev 107:2228–2269

Faraday M (1857) The Bakerian lecture—experimental relations of gold (and other metals) to light. Phil Trans Royal Soc Lond 147:145–181

Fojtik A, Henglein A (1993) Laser ablation of films and suspended particles in a solvent—formation of cluster and colloid solutions. Ber Bunsenges Phys Chem Chem Phys 97:252–254

Hahn A, Barcikowski S (2009) Production of bioactive nanomaterial using laser generated nanoparticles. J Laser Micro/Nanoeng 4:51–54

Hahn A, Barcikowski S, Chichkov B (2008) Influences on nanoparticle production during pulsed laser ablation. J Laser Micro/Nanoeng 3:73–77

Heinze T, Shapira P, Senker J, Kuhlmann S (2007) Identifying creative research accomplishments: methodology and results for nanotechnology and human genetics. Scientometrics 70:125–152

Hodak JH, Henglein A, Giersig M (2000) Laser-induced inter-diffusion in AuAg core–shell nanoparticles. J Phys Chem B 104:11708–11718

Kabashin AV, Meunier M, Kingston C (2003) Fabrication and characterization of gold nanoparticles by femtosecond laser ablation in an aqueous solution of cyclo-dextrins. J Phys Chem B 107:4527–4531

Kamat PV, Flumiani M, Hartland GV (1998) Picosecond dynamics of silver nanoclusters—photoejection of electrons and fragmentation. J Phys Chem B 102:3123–3128

Kimura Y, Takata H, Terazima M, Ogawa T, Isoda S (2007) Preparation of gold nanoparticles by the laser ablation in room-temperature ionic liquids. Chem Lett 36:1130–1131

Kostoff RN, Stump JA, Johnson D, Murday JS, Lau CGY (2006) The structure and infrastructure of the global nanotechnology literature. J Nanopart Res 8:301–321

Kostoff RN, Koytcheff RG, Lau CGY (2007) Global nanotechnology research literature overview. Technol Forecast Soc Change 74:1733–1747

Link S, El-Sayed MA (1999) Spectral properties and relaxation dynamics of surface plasmon electronic oscillations in gold and silver nanodots and nanorods. J Phys Chem B 103:8410–8426

Mafune F, Kohno JY, Takeda Y et al (2002) Growth of gold clusters into nanoparticles in a solution following laser-induced fragmentation. J Phys Chem B 106:8555–8561

Morales AM, Lieber CM (1998) A laser ablation method for the synthesis of crystalline semiconductor nanowires. Science 279:208–211

Pavesi L, Dal Negro L, Mazzoleni C et al (2000) Optical gain in silicon nanocrystals. Nature 408:440–444

Petersen S, Barcikowski S (2009) In situ bioconjugation—single step approach to tailored nanoparticle-bioconjugates by ultrashort pulsed laser ablation. Adv Funct Mater 19:1167–1172

Porter AL, Youtie J, Shapira P, Schoeneck DJ (2008) Refining search terms for nanotechnology. J Nanopart Res 10:715–728

Sattari R, Sajti CL, Khan S, Barcikowski S (2008) Scale-up of nanoparticle production during laser ablation of ceramics in liquid media. In: 27th International conference on applied lasers electro-optics, ICALEO, 20–23 Oct 2008, pp 49–54

Simakin AV, Voronov VV, Shafeev GA (2001) Nanodisks of Au and Ag produced by laser ablation in liquid environment. Chem Phys Lett 348:182–186

Sylvestre JP, Kabashin AV, Sacher E, Meunier M, Luong JHT (2004a) Stabilization and size control of gold nanoparticles during laser ablation in aqueous cyclodextrins. J Am Chem Soc 126:7176–7177

Sylvestre JP, Poulin S, Kabashin AV, Sacher E, Meunier M, Luong JHT (2004b) Surface chemistry of gold nanoparticles produced by laser ablation in aqueous media. J Phys Chem B 108:16864–16869

Tsuji T, Iryo K, Watanabe N (2002) Preparation of silver nanoparticles by laser ablation in solution: influence of laser wavelength on particle size. Appl Surf Sci 202:80–85

Usui H, Shimizu Y, Sasaki T et al (2005) Photoluminescence of ZnO nanoparticles prepared by laser ablation in different surfactant solutions. J Phys Chem B 109:120–124

Voronov VV, Kazakevich PV, Simakin AV, Shafeev GA (2004) Production of copper and brass nanoparticles upon laser ablation in liquids. Quant Electron 34:951–956

Wang JB, Yang GW, Zhang CY et al (2003) Cubic-BN nanocrystals synthesis by pulsed laser induced liquid–solid interfacial reaction. Chem Phys Lett 367:10–14

Zeng HB, Cai WP, Li Y et al (2005) Composition/structural evolution and optical properties of ZnO/Zn nanoparticles by laser ablation in liquid media. J Phys Chem B 109:18260–18266