A bibliometric analysis of highly cited articles in materials science

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The aim of the present study is to identify and analyse the characteristics of the highly cited articles in materials science, including eight *Web of Science* categories: multidisciplinary materials science, coatings and films materials science, biomaterials materials science, ceramics materials science, composites materials science, paper and wood materials science, characterization and testing materials science, and textiles materials science within the publication year from 1900 to 2011 based on *Science Citation Index-Expanded*. Articles that have been cited at least 100 times since publication to 2011 were assessed regarding their distribution in indexed journals. The citation lives of the highly cited articles depending on citations in the publication year, recent years and years after publication were applied for the impact of articles. A new indicator, the *Y*-index, was applied to assess publication quantity and the characteristics of contribution to articles. Results showed that 14,044 highly cited articles were published between 1900 and 2010. Among them, 70% were published in 1990s and 2000s, and 48% originated from the US. *Langmuir* and *Journal of the Electrochemical Society* hosted the highly cited articles. Most top cited articles in the publication year would not be top cited in recent years. *Y*-index results showed that Massachusetts Institute of Technology, USA had high articles publication potential as well as published the most first author and corresponding author articles. Geim and Novoselov who are the 2010 Nobel laureates, published the most potential article in materials science. *Y*-index showed that Inoue and Xia had the highest publication performance but different publication characteristics.

Keywords: Article life, bibliometric analysis, structural materials, *Y*-index.

RESEARCH has long been performed in the area of materials science. In 1900s, researchers published their works in *Philosophical Magazine*, which is one of the most popular journals in the *Web of Science* (*WoS*) categories of multidisciplinary materials science. The contribution to the theory of electrocapillarity was presented in 1913. Measurement of material properties, for example, velocity constant of a unimolecular reaction[1] and viscosity of glasses[2] was the focus in 1920s. Works of great influence were published in the following years, for example, electrochemical polarization[3], dislocations and cracks in anisotropic elasticity[4], yielding of steel sheets containing slits[5], defects in epitaxial multilayers[6] and anomalous low-temperature thermal properties of glasses and spin glasses[7]. In 1980s, nanocrystalline materials became a new research topic[8]. In the last two decades researchers have paid more attention on nanomaterials[9,10] and carbon films[11,12], which have long been studied[13,14].

Recent research focuses would be reflected in its publication output[15]. It has also been pointed out that citation rate is not only a direct measure of the impact or importance of a particular scholarly work, but also provides a marker of its recognition within the scientific community[16]. A common research tool for this analysis is the bibliometric method, which has already been widely applied in many disciplines of science and engineering[17,18]. Analysis of citation rates of top-cited articles reveals useful and interesting information about scientific progress in a research field[19]. Several recent studies have identified and analysed citation classics and top-cited articles in various fields of science and engineering, such as environmental sciences[20], water resources[21], chemical engineering[22] and adsorption[23]. A new bibliometric indicator, the *Y*-index, has also been presented to evaluate the top-cited research works in *Scientometrics*[24]. In terms of top-cited articles, three kinds of citations – total citations since their publication to the end of 2011, total citations in recent single year and total citations in publication year – have been discussed.

In this study, all journal articles with at least 100 total citations since publication to 2011 in materials science were selected as highly cited articles and then analysed with regard to citation histories, total citations, citations in 2011, citations in publication year and journals. Highly cited articles with address information of both first and corresponding authors were also analysed using *Y*-index that was applied to evaluate contributions of individual authors and institutions.

Methodology

The methodology used the Science *Citation Index-Expanded* (*SCI-EXPANDED*) database of Thomson

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Reuters *WoS*. According to *Journal Citation Reports* (*JCR*) of 2011, it indexes 8336 journals with citation references across 176 *WoS* categories in science edition. Total 1,507,125 documents were published in materials science in 8 *WoS* categories – biomaterials materials science (BMS; 25 journals), ceramics materials science (CRMS; 25 journals), characterization and testing materials science (CTMS; 32 journals), coatings and films materials science (CFMS; 18 journals), composites materials science (CPMS; 24 journals), multidisciplinary materials science (MMS; 232 journals), paper and wood materials science (PWMS; 21 journals) and textiles materials science (TMS; 21 journals) within the publication year from 1900 to 2011 based on *SCI-EXPANDED* (updated on 28 December 2012). Document type of article was considered. Altogether 1,297,456 articles were found. Another filter, TC2011 was used to retrieve the articles. The total number of times an article is cited from its publication to the end of 2011 was recorded as TC2011 (refs 21 and 25). TC2011 ≥ 100 selected the highly cited articles. Likewise, C2011, the total number of citations of an article in 2011 and C0, the total number of citations of an article in its publication year were used to characterize the highly cited articles. The records were downloaded into spreadsheet software and manipulated using Microsoft Excel 2007. In the *SCI-EXPANDED* database, the corresponding author is designated as the 'reprint' author; this study uses the term 'corresponding author'. In a single-author article where authorship is unspecified, the single author is both first author and corresponding author. Similarly, in a singly institutional article, the institution is classified as the first author institution and the corresponding author institution. Affiliations in England, Scotland, Northern Ireland and Wales were reclassified as being from the United Kingdom (UK)[26]; those in the Federal Republic of Germany (Fed Rep Ger), German Democratic Republic (Ger Dem Rep), West Germany, Bundes Republik, and Germany were reclassified as being from Germany; in the USSR ESSSR, MOSSR and Russia were reclassified as being from Russia; in Holland and the Netherlands were reclassified as being from the Netherlands; in Yugoslavia and Slovenia were reclassified as being from Slovenia; in Czechoslovakia and Czech Republic were reclassified as being from Czech Republic, and those in Hong Kong before 1997 were included with China[23]. The impact factor (IF2011) of a journal was determined for each article as reported in the *JCR* 2011.

Results and discussion

Effect of time on citation analysis

It has been accepted that how often one's work is cited is a better measure of the impact of an individual's works than how many papers a person has authored[27]. Altogether 14,044 highly cited articles (1.1% of 1,297,456 articles) in materials science in *SCI-EXPANDED* were published between 1900 and 2010. The number of authors per highly cited article in materials science was 3.6 and the largest number of authors per article was 46. The average number of authors per article increased from 1.1 in 1900s to 3.5 in 1990s and 4.7 in 2000s. Citation is useful to identify classic works and high-impact journals[28]. Multiple-authored articles in management science show a statically significant higher citation rate[29], while they are not of higher quality than single-authored articles in astronomy and physics than among the social sciences[30].

Of the 14,044 highly cited articles, 1843 (13%) were written by single author, 3327 (24%) by two authors, 2856 (20%) by three authors, 2173 (15%) by four authors, 1474 (10%) by five authors and 2371 (17%) by more than five authors. High percentage of single-author articles was also found in the highly cited articles in chemical engineering[22]. The number of authors correlates positively with the received citations of a paper over a given period of time, but there was no significant relationship between the number of authors in a highly cited article and its number of citations. Similar trends of the highly cited articles, total publications and total articles during 1900–2010 are shown in Figure 1. Before 1990, 4131 highly cited articles (29% of 14,044 highly cited articles) were published, while 9913 articles (71%) have been published since 1990s. The earliest three highly cited articles[31–33] were published in 1900 in *Philosophical Magazine*. Before 1960, *Philosophical Magazine* published the most highly cited articles. *Journal of the American Ceramic Society*, *Journal of the Electrochemical Society*, *Journal of the Mechanics and Physics of Solids*, *Textile Research Journal*, *TAPPI* and *Proceedings – American*

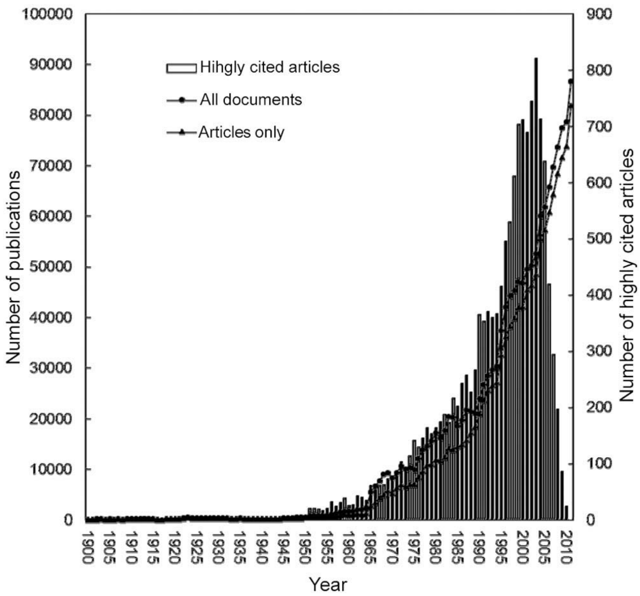

Figure 1. Number of highly cited articles and total publications in materials science.

Table 1. Top 10 journals with more than 350 highly cited articles

Journal	TP (%)	IF2011	TC2011/TP	C0/TP	C2011/TP	Country
Langmuir	1098 (7.8)	4.186	168.6	1.34	16.7	USA
Journal of the Electrochemical Society	1085 (7.7)	2.590	178.0	0.877	10.9	USA
Advanced Materials	877 (6.2)	13.88	187.8	1.941	25.2	Germany
Chemistry of Materials	738 (5.3)	7.286	176.9	1.26	21.0	USA
Nano Letters	711 (5.1)	13.20	199.4	3.86	41.7	USA
Journal of the American Ceramic Society	658 (4.7)	2.272	189.0	0.725	8.78	USA
Biomaterials	590 (4.2)	7.404	166.7	1.55	22.5	The Netherlands
Philosophical Magazine	456 (3.2)	1.510	247.5	1.01	6.65	UK
Journal of Biomedical Materials Research	379 (2.7)	N/A	178.3	0.602	13.2	USA
Nature Materials	359 (2.6)	32.84	251.8	5.680	59.1	UK

TP, Total number of highly cited articles; TC2011, Number of citations till 2011; C2011, Number of citations in 2011; C0, Number of citations in the publication year.

Society for Testing and Materials also contributed to highly cited articles before 1960. The latest highly cited article in materials science was published in 2010. Liang *et al.*[34] from USA had C0 = 88 (ranked second), C2011 = 339 (ranked 15th) and TC2011 = 427 (ranked in 592th).

Journal and WoS subject category

The highly cited articles were published in 257 journals in materials science in *WoS*. Among these, 67 journals (26% of 257 journals) contained only one highly cited article, 25 (10%) journals contained two articles, 15 (5.8%) journals contained three articles, 10 (3.9%) journals contained four articles, 12 (4.7%) journals contained five articles and 128 (50%) journals contained more than five articles. Table 1 lists the top 10 journals with more than 250 highly cited articles. *Langmuir* published most of the highly cited articles (1098; 7.8% of 14,044 highly cited articles). Among the top 10 journals, *Nature Materials* had the highest IF2011, the average TC2011, C0 and 2011. There were 440 (3.1% of 14,044 highly cited articles) highly cited articles published in journals with IF2011 ≥ 20; 3590 (26%) articles were published in journals with 5 ≤ IF2011 < 20; 1996 (14%) articles were published in journals with 3 ≤ IF2011 < 5; 6367 (45%) articles were published in journals with 1 ≤ IF2011 < 3; 265 (1.9%) articles were published in journals with IF2011 < 1 and 1386 (10%) journals had no impact factor in 2011. It should be noted that journals might be merged, for example, in 2003, *Philosophical Magazine* merged from *Philosophical Magazine A – Physics of Condensed Matter, Structure, Defects and Mechanical Properties* and *Philosophical Magazine B – Physics of Condensed Matter Statistical Mechanics, Electronic, Optical and Magnetic Properties*. In 2005, *Journal of Biomedical Materials Research* split into *Journal of Biomedical Materials Research A* and *Journal of Biomedical Materials Research B*. In 2011, *Materials Transactions JIM* was changed to *Materials Transactions*. It was generally expected that articles tend to become highly cited because they are published in high impact journals, that is, in journals of high prestige[35]. Several studies also pointed out that the topmost articles were also published in journals which did not have high impact factors[36,37]. However, the two most frequently cited articles in materials science were published by Kresse and Furthmüller[38], and Oliver and Pharr[39] in *Computational Materials Science* and *Journal of Materials Research*, with IF2011 of 1.574 and 1.434 respectively.

Within the eight materials science-related *WoS* categories, MMS, published the most highly cited articles (10,244; 73%), followed by CFMS (1785; 13%), BMS (1154; 8.2%), CRMS (1108; 7.9%), CPMS (211; 1.5%), PWMS (73; 0.52%), CTMS (50; 0.36%) and TMS (42; 0.30%). Top two articles with respect to TC2011, C0 and C2011 were published in the journals of MMS. It should also be noticed that journals could be classified in two or more categories in *WoS*, for instance, *Langmuir* was listed in multidisciplinary chemistry, physical chemistry, and MMS; thus the sum of percentages was higher than 100%.

Citation life cycles of highly cited articles

The trend of a paper's citations with time has long been studied[40]. In recent years, the citation life cycles of the most frequently cited Essential Science Indicators papers in the subject category of water resources[21], the top-cited adsorption-related articles[23], top-cited articles in chemical engineering in *SCI-EXPANDED*[22], and top-cited research works in *SCI-EXPANDED*[24] have also been studied. The previous works would tend to be cited more frequently irrespective of their actual impact. While more recently, highly compelling articles may not have had sufficient time to generate citation rates representing their overall impact[16]. Total citations of articles were widely applied in most studies. In this study, TC2011, C2011 and C0 were employed to characterize the highly cited articles. Totally 7586 highly cited articles (54% of 14,044 highly cited articles) had no citations in the publication year (C0 = 0), and only 29 articles (0.21%) had at least 30 times citations (C0 ≥ 30). Figure 2 shows the life for the top 10 most cited articles in their publication year (C0 > 40). All articles were published during 2005–2010. Articles with higher citations in the publication year (C0) were likely to be published in recent years. One of the reasons might be that the number of journals in *JCR* (science edition, 2011) increased from 4963 in 1997 to 8336 in 2011. Citations of articles published by Geim and Novoselov[41], Liang *et al.*[34], Reina *et al.*[42] and Chan *et al.*[43] obviously increased after their publication.

The rank of an article by annual citations in recent years (C2011) was studied for the top-cited articles in chemical engineering[22]. In a recent year (2011), totally 582 highly cited articles (4.1% of 14,044 highly cited articles) had no citations (C2011 = 0), and 204 articles (1.5%) had at least 100 times citations (C2011 ≥ 100). The citation life curves of the top eight articles (C2011 > 450) are shown in Figure 3. All these recent top-cited articles were published in 1990s and 2000s, and had increasing trends of citation after their publication. In materials science, article published by Geim and Novoselov[41] in 2007 was not only the most frequently cited article with C0 = 119 citations, but also the most super cited article in 2011 with C2011 = 1678. The number of highly cited articles with at least 100 citations in 2011 (C2011 ≥ 100) was 204 (1.5%), which included 154 articles in 2000s, 24 in 1990s, 16 in 2010s, 3 in 1970s, 2 in 1980s, 2 in 1970s and 1 in 1950s, 1900s and 1920s respectively. All these top-cited articles in C2011 still keep pace with the impact in the area of materials science. Seventy-three per cent of the top 100 articles by C2011 were not ranked in top 100 by C0. That indicates the highly cited articles would not always have high impact or visibility in research. Similar result was also observed that since 1988, 94% of the 50 most frequently cited articles published in the *American Journal of Roentgenology* have changed their rankings[44].

Information of total citations from *WoS* was updated weekly and applied widely in most studies. In this study, the total number of times an article was cited from its publication to the end of 2011 (TC2011) was used[21]. The advantage of this indicator is its invariance, not updating with time[23]. The citation lives of the top seven articles (TC2011 > 2500) are shown in Figure 4. Earlier publications such as Dugdale[5], Anderson *et al.*[7], and Matthews and Blakeslee[6] had a long impact history, but much less impact in recent years, especially the two articles published in 1970s. Sharply increasing trends of citation could be found for the articles published by Kresse and Furthmüller[38], Oliver and Pharr[39], and Geim and Novoselov[41]. In materials science, 'The rise of graphene'[41] published in *Nature Materials* by Geim and Novoselov[41] from University of Manchester, UK, not only had the highest citation in the publication year (C0) and recent years (C2011), but also had an extremely high increasing trend of citations. Geim and Novoselov received the Nobel Prize in physics in 2010 for their groundbreaking experiments regarding the two-dimensional material graphene. The top three articles in TC2011 were also the top three in C2011, including 'Efficiency of *ab initio* total energy calculations for metals and semiconductors using a plane-wave basis set'[38], 'An improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments'[39], and 'the rise of graphene'[41]. The article by Kresse and Furthmüller[38] in 1996 has been a high impact article which ranked

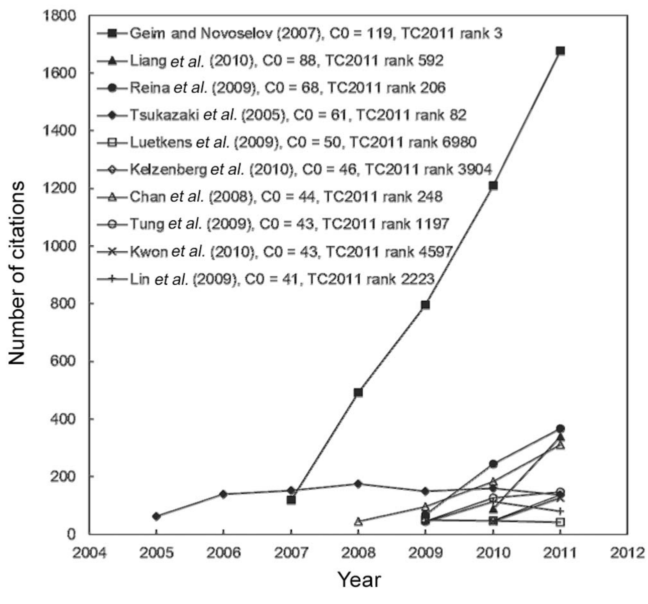

Figure 2. Life of the top 10 most cited articles in their publication year (C0 > 40).

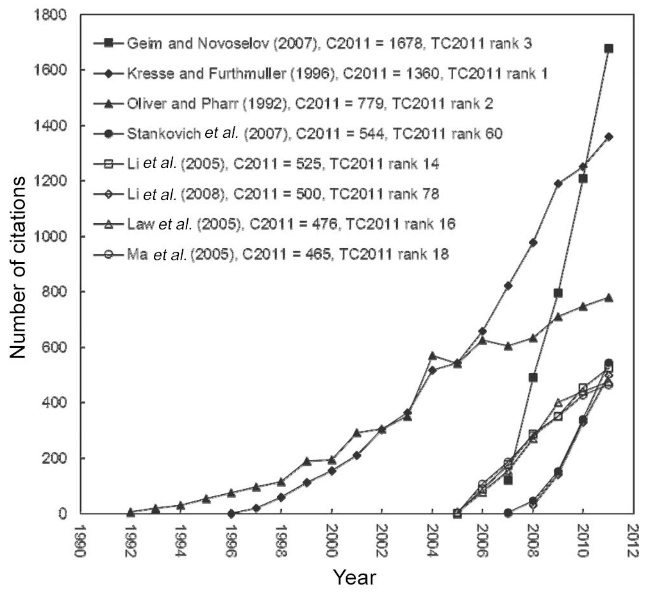

Figure 3. Life of the top 8 most cited articles in 2011 (C2011 > 450).

Table 2. Eleven most frequently cited articles in materials science (TC2011 > 2000)

Rank (TC2011)	Rank (C2011)	Rank (C0)	Author	Year	Journal	Reference
1 (8545)	2 (1360)	6459 (0)	Kresse, G.	1996	*Computational Materials Science*	38
2 (6941)	3 (779)	846 (5)	Oliver, W. C.	1992	*Journal of Materials Research*	39
3 (4294)	1 (1678)	1 (119)	Geim, A. K.	2007	*Nature Materials*	41
4 (3071)	299 (84)	3789 (1)	Matthews, J. W.	1974	*Journal of Crystal Growth*	6
5 (2529)	2335 (29)	487 (7)	Anderson, P. W.	1972	*Philosophical Magazine*	7
6 (2528)	74 (149)	6459 (0)	Dugdale, D. S.	1960	*Journal of the Mechanics and Physics of Solids*	5
7 (2507)	23 (267)	250 (10)	Inoue, A.	2000	*Acta Materialia*	52
8 (2162)	22 (273)	173 (12)	Brabec, C. J.	2001	*Advanced Functional Materials*	53
9 (2153)	86 (142)	2462 (2)	Anstis, G. R.	1981	*Journal of the American Ceramic Society*	54
10 (2105)	187 (102)	6459 (0)	Cross, L. E.	1987	*Ferroelectrics*	55
11 (2035)	102 (134)	3789 (1)	Fulcher, G. S.	1925	*Journal of the American Ceramic Society*	2

TC2011, Number of citations till 2011; C2011, Number of citations in 2011; C0, Number of citations in publication year.

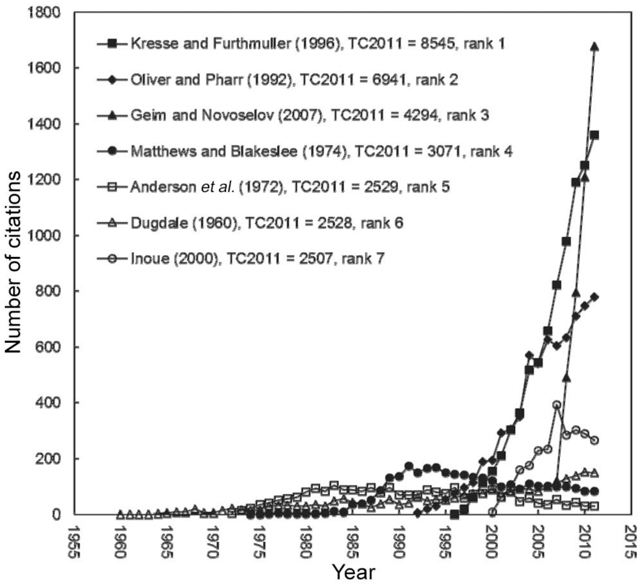

Figure 4. Life of the top 7 most cited articles (TC2011 > 2500).

first by TC2011 and second by C2011. The article by Geim and Novoselov[41] in 2007 is the most potential article which ranked first by C2011 and C0, and second by TC2011.

Table 2 presents the top 11 articles cited more than 2000 times (TC2011 > 2000). Among these three articles (27%) were published in 2000s, two (18%) in 1990s, and six (55%) before 1990. The first article cited more than 2000 times was published in 1925, and the latest one was published in 2007. The journals in which these articles published were *Journal of the American Ceramic Society* (IF2011 = 2.272) with two articles, and one for each of *Computational Materials Science* (IF2011 = 1.574), *Journal of Materials Research* (IF2011 = 1.434), *Nature Materials* (IF2011 = 32.841), *Journal of Crystal Growth* (IF2011 = 1.726), *Philosophical Magazine* (IF2011 = 1.510), *Journal of the Mechanics and Physics of Solids* (IF2011 = 2.806), *Acta Materialia* (IF2011 = 3.755), *Advanced Functional Materials* (IF2011 = 10.179), and *Ferroelectrics* (IF2011 = 0.391) respectively. There was no strong relation between total citations and impact factor of journals for the most super articles in materials science. Impacts of the highly cited articles have been changed after their publication. The most super articles in TC2011 had low citation in their publication year. Article citation life in Figures 2–4 could give a history of the impact of an article from different angles based on three indicators, including TC2011, C2011 and C0.

Publication performances: institutions and authors

Among the 14,044 highly cited articles in materials science, 1064 did not have information on author address in *WoS*. Of all the 12,980 articles with author address, 10,920 (84%) were country-independent articles from 52 countries and 2060 (16%) were internationally collaborative articles from 70 countries. USA published the most number of articles, i.e. 6,292 (48% of 12,980 articles), followed by Japan (1452 articles), Germany (1263), the UK (1115), France (780), China (661) and Canada (387). The seven major industrial countries (G7: USA, Japan, the UK, Germany, France, Canada and Italy) published 10,608 articles (82% of 12,980 articles). Domination of articles from the developed countries was not surprising, since this pattern occurs in other scientific fields as well[45,46]. Furthermore, USA was also the most frequent partner accounting for 53% of 2060 internationally collaborative articles followed by Germany (486 articles; 24%), the UK (352; 17%), France (292; 14%), Japan (291; 14%), China (235; 11%), Switzerland (152; 7.4%), The Netherlands (138; 6.7%), Canada (132; 6.4%), South Korea (108; 5.2%) and Italy (100; 4.9%).

Comparison of publication performance of authors[47], institutions[48] and countries[25] was made using bibliometric indicators. Recently, the *Y*-index has been presented to characterize publications of authors, institutions and countries[22,24]. It is related to important authorship which are the number of first author publications (FP) and corresponding author publications (RP). The *Y*-index with two parameters (j, h), assesses both the publication quantity and characteristics of contribution as a single index, and is defined as

$$j = \text{FP} + \text{RP}, \quad (1)$$

$$h = \tan^{-1}\left(\frac{\text{RP}}{\text{FP}}\right), \quad (2)$$

j indicates publication quantity with first and corresponding author articles only, and is calculated using the number of first authored articles and corresponding authored articles as shown in eq. (1). When j is large, it means its Y-index is located far away from the origin of the polar coordinates. It indicates that one published more articles as 'important author'. In order to determine the location of the Y-index in polar coordinates, another parameter h is necessary. h is a publication characteristics constant that externalizes the role of a author. It introduces the distribution of the number of the first authored articles and the corresponding authored articles. When the number of the first authored articles and corresponding authored articles are the same, the Y-index is located in the 45° (0.7854 rad) line. Thus h could be calculated using eq. (2). When $h > 0.7854$, it means one published more corresponding author articles, and when $h < 0.7854$, it means one published more first author articles. When $h = 0$, j is the number of first author articles, and when $h = \pi/2$, j is the number of corresponding author articles.

Of the 14,044 highly cited articles, 12,980 with both first author and corresponding author address information in *WoS* were used to calculate the Y-index for institutions. For individual authors, 11,374 articles with both first author and corresponding author names were employed to calculate the Y-index. Table 3 shows the top 22 institutions with no less than 100 highly cited articles (TP ≥ 100), ranked according to the value of TP. The compared indicators include the constants of the Y-index (j, h), the number and percentage of single-institution articles and inter-institutionally collaborative articles as well as first author and corresponding author. Massachusetts Institute of Technology (MIT), USA published 298 first author and 294 corresponding author articles in materials science, and had the highest j of Y-index (592, 0.7786), followed by Pennsylvania State University, USA ($j = 347$) which also ranked second in single-institution articles, first author articles, and corresponding author articles, but ranked sixth in total articles. MIT ranked first among all indicators in Table 1, except the single-author articles, while University of Cambridge, UK published the most single-author articles. Both Stanford University, USA and Pennsylvania State University had h greater than 0.7854, indicating these institutions published more corresponding author articles. There were 12 institutions publishing more first author articles with $h < 0.7854$. Industrial laboratories USA such as IBM Corporate, Oak Ridge National Laboratory, and Sandia National Laboratory also ranked among top 22 with respect to TP. The article entitled 'an improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments'[39] by Oliver from Oak Ridge National Laboratory and Pharr from Rice University ranked second with TC2011 = 6941. The article entitled 'Defects in epitaxial multilayers: I. Misfit dislocations'[6] by Matthews and Blakeslee from IBM Corporate ranked fourth with TC2011 = 3071.

It has been reported that the first author is the person who contributes most to the work and writing of the article[49]. The corresponding author is perceived as one contributing significantly to the article independently of the author position[50]. A total of 11,374 highly cited articles in materials science field contributed by 25,465 authors from 72 countries. Only 5984 authors (23% of 25,465 authors), had both first and corresponding author articles, while 17,117 (67%) authors had no first author articles and 18,125 (71%) authors had no corresponding author article. Particularly, 455 authors (7.6% of the 5984 authors) had $h > 0.7854$, and 317 authors (5.3%) had $0 < h < 0.7854$, while 5212 (87%) authors had the same numbers of first author and corresponding author articles ($h = 0.7854$). Figure 5 shows distribution of the Y-index (j, h) of the top 17 authors with $j \geq 20$. Each dot represents one value that could be a single author or many authors. j is publication intensity constant; an author with higher j indicates more articles as first or corresponding authors, and is more likely to take leadership role in more articles. Inoue, A. had the highest j of 73; he published 74 highly cited articles, including 38 first author and 35 corresponding author articles ($h = 0.7443$), followed by Xia, Y. N. ($j = 70$). h, a publication characteristics constant, differentiates the nature of leadership role. h, could help obtain the different proportions of corresponding author articles to first author articles. Inoue, A. ($h = 0.7443$) and Xia, Y. N. ($h = 1.494$) has similar j values. However, they had different publication characteristics. It is also helpful to distinguish the different performances of authors, especially when j values of the authors is the same. For example, the j values of Langdon, T. G., Wang, Z. L. and Suresh, S. were all the same (27). Nevertheless, h of Langdon, T. G. was 1.347, Wang, Z. L. was 1.234 and Suresh, S. was 1.107. Langdon, T. G. had greater proportion of corresponding author articles to first author articles, followed by Wang, Z. L. and Suresh, S. Furthermore, within these 22 authors, Tvergaard, V. and Inoue, A. were the only two who had more first author articles than corresponding author articles ($h < 0.7854$). Five authors in Figure 5 were just on the boundary line ($h = 0.7854$), with the same number of first author and corresponding author articles. A bias would appear in authorship analysis because two or more authors may have the same name, or authors used different names in their publications (e.g. names change due to marriage)[25]. Therefore, it is strongly recommended to create an 'international identity number' which is offered to an individual person when he/she publishes the first paper in *WoS* listed journals[51].

Table 3. Top 22 institutions with no less than 100 highly cited articles (TP ≥ 100)

Institution	TP	TPR (%)	IPR (%)	CPR (%)	FPR (%)	RPR (%)	SPR (%)	*h*	Rank (*j*)
Massachusetts Institute of Technology, USA	354	1 (2.7)	1 (2.5)	1 (3.1)	1 (2.3)	1 (2.3)	4 (1.3)	0.7786	1 (592)
Harvard University, USA	242	2 (1.9)	5 (1.4)	3 (2.7)	5 (1.2)	5 (1.2)	14 (0.72)	0.7822	5 (315)
University of California, Berkeley, USA	230	3 (1.8)	11 (1.1)	2 (2.8)	3 (1.3)	3 (1.3)	7 (0.94)	0.7824	3 (331)
Tohoku University, Japan	209	4 (1.6)	3 (1.5)	8 (1.7)	4 (1.2)	4 (1.2)	5 (1.2)	0.7854	4 (322)
Chinese Academy of Sciences, China	202	5 (1.6)	9 (1.2)	4 (2.2)	7 (1.1)	7 (1.1)	140 (0.14)	0.7854	7 (288)
Pennsylvania State University, USA	201	6 (1.5)	2 (1.7)	12 (1.3)	2 (1.3)	2 (1.3)	14 (0.72)	0.7883	2 (347)
University of California, Santa Barbara, USA	194	7 (1.5)	10 (1.2)	5 (2.0)	9 (1.1)	9 (1.0)	27 (0.58)	0.7706	9 (270)
University of Cambridge, UK	191	8 (1.5)	6 (1.3)	7 (1.7)	6 (1.2)	6 (1.2)	1 (2.2)	0.7755	6 (303)
IBM Corporate, USA	172	9 (1.3)	4 (1.4)	19 (1.2)	8 (1.1)	8 (1.1)	2 (1.9)	0.7782	8 (276)
Stanford University, USA	153	10 (1.2)	12 (1.1)	13 (1.3)	12 (0.91)	11 (0.92)	27 (0.58)	0.7896	11 (237)
University of Illinois, USA	148	11 (1.1)	15 (0.89)	9 (1.5)	15 (0.82)	14 (0.82)	84 (0.22)	0.7854	14 (212)
University of Texas, USA	148	11 (1.1)	14 (0.90)	10 (1.5)	14 (0.84)	15 (0.79)	N/A	0.7571	14 (212)
Kyoto University, Japan	143	13 (1.1)	7 (1.2)	28 (1.0)	12 (0.91)	12 (0.91)	14 (0.72)	0.7854	12 (236)
Northwestern University, USA	143	13 (1.1)	13 (0.91)	11 (1.4)	11 (0.92)	13 (0.90)	52 (0.36)	0.7769	12 (236)
University of Washington, USA	139	15 (1.1)	8 (1.2)	32 (0.90)	10 (0.93)	10 (0.92)	N/A	0.7812	10 (241)
CNRS, France	124	16 (1.0)	48 (0.38)	6 (1.9)	23 (0.54)	23 (0.52)	84 (0.22)	0.7709	23 (138)
University of Pennsylvania, USA	117	17 (0.90)	18 (0.66)	15 (1.3)	18 (0.61)	18 (0.61)	10 (0.79)	0.7854	18 (158)
Rice University, USA	116	18 (0.89)	18 (0.66)	17 (1.3)	16 (0.69)	16 (0.69)	84 (0.22)	0.7854	16 (178)
California Institute of Technology, USA	104	19 (0.80)	18 (0.66)	26 (1.0)	22 (0.55)	22 (0.55)	33 (0.50)	0.7854	22 (144)
Oak Ridge National Laboratory, USA	102	20 (0.79)	34 (0.48)	15 (1.3)	31 (0.49)	31 (0.47)	27 (0.58)	0.7693	32 (124)
Sandia National Laboratory, USA	100	21 (0.77)	30 (0.53)	22 (1.2)	21 (0.57)	21 (0.57)	14 (0.72)	0.7854	21 (148)
University of Tokyo, Japan	100	21 (0.77)	40 (0.43)	13 (1.3)	31 (0.49)	30 (0.48)	84 (0.22)	0.7774	31 (125)

TP, Total number of highly cited articles; TPR (%), IPR (%), CPR (%), FPR (%), RPR (%) and SPR (%), Rank and percentage of total articles, single institution articles, inter-institutionally collaborative articles, first author articles, corresponding author articles, single author articles in their total articles; *j* and *h*, Constants of *Y*-index; N/A, Not available.

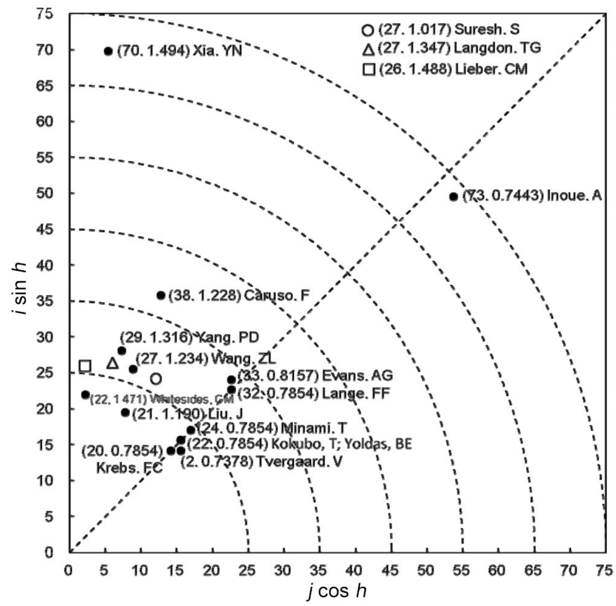

Figure 5. Top 17 authors with *Y*-index ($j \geq 20$).

Conclusions

In total, 14,044 highly cited articles which had at least 100 citations since publication to 2011 were found in the area of materials science *SCI-Expanded* from 1900 to 2010. Seventy per cent of the highly cited articles were published in 1990s and 2000s in 257 journals. Thirty-seven per cent of the highly cited articles were published by single or two authors. *Langmuir* and *Journal of the Electrochemical Society* published the most highly cited articles. Highly cited articles were published not only in high impact factor journals, but also in lower impact factor journals. In terms of *j* of *Y*-index, top three institutions were MIT, Pennsylvania State University and University of California, Berkeley. *h* of *Y*-index, showed that highly productive institutions had similar number of first and corresponding author articles. Inoue, A. had the highest publication potential, and published more first author articles than corresponding author articles. Xia, Y. N. published the most corresponding author articles. The article by Geim and Novoselov[41] in 2007, who won Nobel laureates in physics in 2010, ranked first by three indicators of citations in publication year (C0), recent year (C2011), and citations since publication to 2011 (TC2011), and may be the one with the greatest influence in the area of materials science.

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Received 9 June 2014; revised accepted 14 July 2014