THIN FILMS RESEARCH: A SCIENTOMETRIC ASSESSMENT OF INDIAN PUBLICATIONS DURING 2009-18

S.M. Dhawan
B.M. Gupta
Rajpal Walke
Asha Rani

S. M. Dhawan
Formerly with CSIR-NPL, New Delhi 110012, India
smdhawan@yahoo.com

B. M. Gupta
Formerly with CSIR-NISTADS, New Delhi 110012, India
bmgupta1@gmail.com

Rajpal Walke
Sr. Technical Officer (3) CSIR-NPL, New Delhi-110012, India
rajpalw@yahoo.com

and

Asha Rani
CSIR-CSIO, Sector 30-C, Chandigarh.

The paper presents a quantitative and qualitative analysis of thin films research in India vis-a-vis the world. The publications data for the study was sourced from Scopus international bibliographical and citation database during 2009-18. The study profiles top 10 most productive countries in the subject, top 20 most productive research organizations, and 15 most productive authors. The study presents distribution of research by subject areas that intersect with thin films and by source journals. The study finds that the China and the USA are the world leader in the subject, followed by South Korea, Japan, India and others. India registered 11.04% annual average growth in the subject, five times the world average growth of 2.20%. India contributed 8.55% share of its output towards global share, 23.47% towards international collaborative papers. It averaged citations impact of 8.73 citations per paper. India contributed 4.12% share of its output as highly cited papers. Shivaji University, Kolhapur has emerged as the top ranking research organization in thin films research in the country.

Keywords: Thin films, materials science, Indian publications, Bibliometric indicators, Scientometrics, Bibliometric

INTRODUCTION

Thin films research is a multidisciplinary research field involving disciplines such as materials science, surface science, and applied physics. Over the years it has emerged as a unified discipline of scientific endeavor[1]. A thin film is a layer of material ranging in thickness from fractions of a nanometer (monolayer) to several micrometers [2]. A solid material is said to be in thin film form when it is built up as a thin layer on a solid support, called substrate, ab initio by controlled condensation of the individual atomic, molecular, or ionic species, either directly by a physical process, or via a chemical and/or electrochemical reaction. Since individual atomic, molecular or ionic species of matter may exist either in the vapor or in the liquid phase, the techniques of thin film deposition have been classified as

a) vapor phase deposition and b) liquid-phase/ solution deposition [3]. Physical properties of thin films material deviate from that of the corresponding bulk materials because of small size of their thickness, large surface-to-volume ratio, and unique physical structure as a direct consequence of the growth process. Some of the phenomena that arise as a natural consequence of small thin films thickness are optical interference, electronic tunneling through an insulating layer, high resistivity and low temperature coefficient of resistance, increase in critical magnetic field and critical temperature of a superconductor, the Josephson effect, and planar magnetization. The high surface-to-volume ratio of thin films, mainly due to their small thickness and microstructure, can influence a number of phenomena such as gas adsorption, diffusion, and catalytic activity. Similarly, enhancement of superconducting transition temperature, corrosion resistance, hardness, thermo power, and optical absorption arise in thin films from such certain materials as having metastable disordered structures[3].

LITERATURE REVIEW

Just a few studies are currently available in the literature on the bibliometric assessment of thin films research. Patil[4] examined thin films research output from India during 2000-2015, using parameters such as growth, document type, productivity and impact of most productive organizations and authors, preferred sources of publications and contribution of major collaborative partners. Guo, Huang and Porter[5] studied the nanotechnology enhanced thin film solar cells research and profiles the research patterns via 'tech mining' to capture key technological attributes, leading actors and networks and also compared the leading countries and key organizations, in terms of R&D quantity, impact and diversity. Bhattacharya and Meyer[6] analyzed patent citations, publication and patent outputs of multinational corporations (MNCs) in thin films technology. They explored different characteristics of knowledge production and knowledge utilization of these firms. Bhattacharya, Kretschmer and Meyer[7] presented a methodology for studying the interactions between science and technology based on patent citation and co-word analysis.

OBJECTIVES OF THE STUDY

The main objective of this study is to evaluate India's research performance in thin films field. The publications and citation data for the study has been sourced from Scopus international database covering the period 2009-18. The specific objectives of the study are:

1. To study the research output of India vs the world and of top 10 most productive countries in thin films research;
2. To study the annual growth rate, global publication share, citation impact and collaboration profile of India in thin films research;
3. To study the distribution of India's publications output by broad subject areas, by sub-areas of thin films research and by thin films applications;
4. To study the publication productivity and citation impact of top 20 organizations and 15 authors from India in the subject;
5. To study the distribution of papers by source journals and identify the leading productive journals; and

6. To study the bibliographic characteristics of highly cited papers.

METHODOLOGY

Publications data needed for the study was retrieved on 8 March 2019 from Scopus (http://www.scopus.com) database. The retrieval strategy utilized for the purpose included keyword "thin films" in field tags "Keyword" or "Article Title". The time period was limited to '2009-18' as shown below. The search yielded 148374 global records. The above main search string was further restricted to individual countries by name in "country tag", in order to obtain publication data on top 10 most productive countries (including India) in the subject. The search string yielded 12681 records as India's output during 2009-18. The search string on India was further refined by using analytical provisions as defined in Scopus database such as "subject area tag", "country tag", "source title tag", "journal title name" and "affiliation tag". Accordingly, information on distribution of publications was obtained by subject, collaborating countries, author-wise, organization-wise and journal-wise. Citation to publications was collected from date of publication till 8 March 2019.

((KEY("thin films") OR TITLE("thin films") OR SRCTITLE ("thin films")) AND PUBYEAR > 2008 AND PUBYEAR < 2019

(KEY("thin films") OR TITLE("thin films") OR SRCTITLE("thin films")) AND PUBYEAR > 2008 AND PUBYEAR < 2019 AND (LIMIT-TO (AFFILCOUNTRY, "India"))

ANALYSIS AND RESULTS

As seen from Scopus database, thin films research conducted across the world accumulated a total of 148374 publications during the 10-year period 2009-18. During the same period, India contributed a total of 12681 publications to the world literature in the subject, accounting for 8.55% global publication share. India registered faster 11.04% annual average growth, five times that of the world (2.20% growth) in the subject. India's annual output increased from 702 in 2009 to 1704 publications in 2018, and that of the

Table 1: Global Vs. India: Publications Output in Thin Films Research during 2009-18

Period	World	India					
	TP	TP	TC	CPP	ICP	%ICP	%TP
2009	12468	702	13295	18.94	177	25.21	5.63
2010	13728	822	14050	17.09	222	27.01	5.99
2011	14967	1114	14617	13.12	247	22.17	7.44
2012	14743	1063	13372	12.58	253	23.80	7.21
2013	15494	1291	13975	10.82	276	21.38	8.33
2014	15167	1438	13333	9.27	326	22.67	9.48
2015	15517	1345	11050	8.22	296	22.01	8.67
2016	15672	1556	9347	6.01	375	24.10	9.93
2017	15585	1646	5954	3.62	388	23.57	10.56
2018	15033	1704	1700	1.00	416	24.41	11.34
2009-13	71400	4992	69309	13.88	1175	23.54	6.99
2014-18	76974	7689	41384	5.38	1801	23.42	9.99
2009-18	148374	12681	110693	8.73	2976	23.47	8.55

world it increased from 12468 to 15033 publications during the same period (Table 1). India's 5-year absolute growth computed between 2009-13 and 2014-18 was 54.03%. It implies that the country growth in the subject during second half of the study period 2014-18 was much faster compared to its growth during 2009-13.

Thin films publications by India registered citation impact of 8.73 citations per publication (CPP) covering the period 2009-18; its 5-year impact in 2009-13 was 13.88 CPP which dropped to 5.38 CPP in 2014-18 (Table 1).Of the total global publications output in the subject, 77.80% (9866) was published as articles, 19.75% (2504) as conference papers, 0.86% (109) as reviews, 0.71% (90) as book chapters, 0.36% (46) as articles in press and others as erratum (38), letters (11), books and notes (7 each) and editorials (2).

International Collaboration

India contributed nearly 1/4th (23.47%) of its national output (12681) in thin films research as international collaborative papers (2796) during 2009-18, of which 86.42% resulted from its collaboration with top 10 countries in the subject. Amongst top 10 collaborating countries, India's collaboration was the largest with South Korea (30.04% share of 2976 ICP papers), followed by USA (15.94%), Germany and Japan (6.97% and 6.56%), France (5.89%), Saudi Arabia, United Kingdom and Taiwan (4.99%, 4.86% and 4.82%), Singapore (3.22%) and Italy (2.91%.) (Table 2, Fig 1). India's collaboration with top 10 countries was dynamic, changing in publication quantity over time. Its collaborationwith Saudi Arabia (1.66%), Japan (0.22%) and United Kingdom (0.18%) witnessed marginal rise (0.18% - 1.66%) between 2009-13 and 2014-18. With countries like France

Fig 1: Thin Films Research - India's Top 10 Collaborating Partner Countries - 2009-18

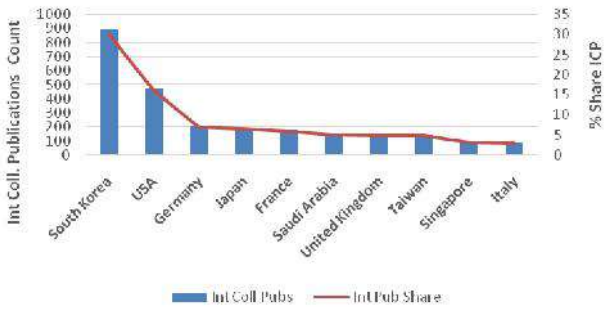

Table 2: Thin Films Research - India's Top 10 Collaborating Partner Countries 2009-18

Sl. No.	Collaborative Country	Number of ICP			Share of ICP		
		2009-13	2014-18	2009-18	2009-13	2014-18	2009-18
1	South Korea	357	540	897	30.38	29.98	30.04
2	USA	191	285	476	16.26	15.82	15.94
3	Germany	108	100	208	9.19	5.55	6.97
4	Japan	75	119	194	6.38	6.61	6.50
5	France	108	68	176	9.19	3.78	5.89
6	Saudi Arabia	47	102	149	4.00	5.66	4.99
7	United Kingdom	56	89	145	4.77	4.94	4.86
8	Taiwan	67	77	144	5.70	4.28	4.82
9	Singapore	43	53	96	3.66	2.94	3.22
10	Italy	42	45	87	3.57	2.50	2.91
	Rest of the Countries	81	323	404			13.58
	World Total	1175	1801	2976			
ICP=International Collaborative Papers							

(5.42%), Germany (3.64%), Taiwan (1.43%), Italy (1.08%), Singapore (0.72%), USA (0.43%) and South Korea (0.40%) its collaboration witnessed modest to marginal decline (0.40% - 5.42%) during the same period.

Top 10 Most Productive Countries in the World in Thin Films Research

India is the 5th most productive country in the world in thin films research accounting for 10.54% global publications share during 2009-18. China ranks top with 19.61% share, followed by the USA (17.17%), South Korea and Japan (9.75% and 9.37%), India (8.54%), Germany (7.08%) and four other countries from 2.36% to 5.24% during 2009-18. During the period between 2009-13 and 2014-18, India, China, United Kingdom and Italy witnessed marginal increase in their 5-year research productivity (by 0.14% to 3.00%), whereas countries like Taiwan, South Korea, Germany and France witnessed marginal decline (from 0.23% to 1.867%) (Table 3, Fig 2).

Table 3: Top 10 Most Productive Countries in the World in Thin Films Research 2009-18

Sl. No.	Name of the Country	Number of Papers			Share of Papers		
		2009-13	2014-18	2009-18	2009-13	2014-18	2009-18
1	China	13143	15953	29096	18.41	20.73	19.61
2	United States	12894	12584	25478	18.06	16.35	17.17
3	South Korea	7314	7155	14469	10.24	9.30	9.75
4	Japan	7352	6555	13907	10.30	8.52	9.37
5	India	4986	7683	12669	6.98	9.98	8.54
6	Germany	5197	5303	10500	7.28	6.89	7.08
7	Taiwan	4435	3346	7781	6.21	4.35	5.24
8	France	3443	3531	6974	4.82	4.59	4.70
9	United Kingdom	2447	2938	5385	3.43	3.82	3.63
10	Italy	1635	1874	3509	2.29	2.43	2.36
	Total	62846	66922	129768	88.02	86.94	87.46
	World Total	71400	76974	148374			

Subject-Wise Distribution of India's Research Output

Publications output by India in thin films research was distributed across six major disciplines (as identified in Scopus database classification) in order to determine top areas of research in the subject. Materials science accounts for the highest publications share (64.51%) intersecting with thin films research, followed by physics & astronomy (59.59%), engineering (38.81%) and 3 other major subjects with publications share between 4.98% and 18.53% during the period 2009-18. Five-year change in research across select disciplines was measured and compared on activity index measure. Such select disciplines that witnessed increase in their activity index above world average (value 100) during 2009-13 to 2014-18

include: materials science (from 99.13 to 100.57), engineering (from 95.32 to 103.04), chemistry (from 95.77 to 102.74), chemical engineering (from 67.97 to 120.80) and energy (from 82.40 to 111.43). Physics and astronomy witnessed drop in its activity index to below the world average (from 106.83 to 95.57) during the period. Energy registered the highest citation impact per paper (12.32), followed by chemical engineering (11.53), chemistry (11.34), materials science (10.01), physics & astronomy (7.91) and engineering (6.45) during 2009-18 (Table 4).

Table 4: Subject-Wise Breakup of India's Publications in Thin Films Research during 2009-18

Sl. No.	Subject*	Number of Papers (TP)			Activity Index		TC	CPP	%TP
		2009-13	2014-18	2009-18	2009-13	2014-18	2009-18		
1	Materials Science	3192	4988	8180	99.13	100.57	81885	10.01	64.51
2	Physics & Astronomy	3178	4379	7557	106.83	95.57	59748	7.91	59.59
3	Engineering	1847	3075	4922	95.32	103.04	31749	6.45	38.81
4	Chemistry	886	1464	2350	95.77	102.74	26659	11.34	18.53
5	Chemical Engineering	320	876	1196	67.97	120.80	13786	11.53	9.43
6	Energy	205	427	632	82.40	111.43	7786	12.32	4.98
	Total of India	4992	7689	12681					
* There is overlapping of literature covered under various subjects									
TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper									

Classification of Thin Films Research

Amorphous thin films research accounted for largest share (7.41%) of the thin films research by India, followed by Nano crystalline thin films (6.58%), polycrystalline thin films (4.68%), epitaxial thin films (1.32%) and single crystals thin films (0.99%) during 2009-18. Polycrystalline thin films registered the highest citation impact per paper (13.33), followed by nano- crystalline thin films (10.99), amorphous thin films (9.18), single crystal thin films (9.03) and epitaxial thin films (7.71) during 2009-18 (Table 5).

Table 5: Classification of Indian Thin Films literature by Types of Thin Films Research 2009-18

Sl. No.	Type of Thin Films	Total Papers (TP)			Share of Total Papers			TC	CPP
		2009-13	2013-18	2009-18	2009-13	2013-18	2009-18	2009-18	
1	Single Crystals	56	69	125	1.12	0.90	0.99	1129	9.03
2	Epitaxial	71	97	168	1.42	1.26	1.32	1296	7.71
3	Polycrystalline	362	231	593	7.25	3.00	4.68	7903	13.33
4	Amorphous	414	526	940	8.29	6.84	7.41	8626	9.18
5	Nano crystalline	436	398	834	8.73	5.18	6.58	9167	10.99
		4992	7689	12681					

India's publications output in the subject were analyzed in terms of distribution by deposition-type technologies. Physical-chemical process contributed the largest share (895 publications and 7.06% share), followed by chemical processes (783 publications and 6.17% share) and physical processes (724 publications and 5.71% share). Physical-chemical process includes sputtering process (593 papers) and plasma processes (363 papers). Similarly,

chemical processes includes gas-phased (687 papers), liquid phase (62 papers) and mechanical processes (42 papers). Similarly physical process includes vacuum evaporation (278 papers) and molecular beam epitaxy (436 papers). Physical process research papers accounted for the highest citation impact per paper (10.74), followed by chemical process (7.83) and physical-chemical process (7.01) [Table 6].

Table 6: Classification of Indian Thin Films Literature in Terms of Deposition Technologies, 2009-18

Sl. No.	Deposition Methods	Number of Papers			Share of Papers			TC	CPP
		2009-13	2014-18	2009-18	2009-13	2014-18	2009-18		
1	Physical Methods	395	329	724	7.91	4.28	5.71	7773	10.74
1.1	Vacuum Evaporation	200	78	278	4.01	1.01	2.19	3193	11.49
1.2	Molecular Beam Epitaxy	262	174	436	5.25	2.26	3.44	5948	13.64
2	Chemical Methods	397	386	783	7.95	5.02	6.17	6127	7.83
2.1	Gas Phased Chemical Process	351	336	687	7.03	4.37	5.42	5119	7.45
2.1.1	Chemical Vapour Deposition	181	228	409					
2.1.2	Ion Implantation	146	109	255					
2.1.3	Thermal Oxidation	12	6	18					
2.2	Liquid Phase Chemical Process	30	32	62	0.60	0.42	0.49	545	8.79
2.2.1	Electrophoretic Plating	12	15	27					
2.2.2	Electroplating	10	5	15					
2.2.3	Electroless Plating	1	6	7					
2.3	Mechanical Processes	17	25	42	0.34	0.33	0.33	512	12.19
2.3.1	Liquid Phase Epitaxy	0	2	2					
2.3.1	Sol-Gel Method	17	23	40					
3	Physical-Chemical Process	356	539	895	7.13	7.01	7.06	6272	7.01
3.1	Sputtering	223	370	593	4.47	4.81	4.68	4219	7.11
3.1.1	Reactive Sputtering	7	30	37	0.14	0.39	0.29	229	6.19
3.1.2	Magnetron Sputtering	147	200	347	2.94	2.60	2.74	2690	7.75
3.1.3	Ion Beam Sputtering	12	20	32	0.24	0.26	0.25	282	8.81
3.1.4	RF Sputtering	31	51	82	0.62	0.66	0.65	502	6.12
3.2	Plasma Processes	178	185	363	3.57	2.41	2.86	2532	6.98
	Total	4992	7689	12681					

Distribution by Applications of Thin Films Research

On classifying India's research output by thin films application, it was observed that solar cell application contributed the largest publication share (8.25%), followed by sensors (7.23%), optical coatings (3.08%), catalysis (1.40%), batteries (0.58%), microelectronic devises (0.26%) and other applications (from 0.01% to 0.25%) during 2009-18. India witnessed increase in research output in 7 application areas (from 0.01% to 5.34%), compared to decline in 2 areas - catalysis and protective coatings (from 0.06% to 0.28%) during the period between 2009-13 to 2014-18. Protective coatings registered the highest citation impact paper (16.17), followed by catalysis (14.59), batteries (12.62), sensors (12.42), solar cells (9.95), optical coating (9.54), etc. during 2009-18 (Table 7).

Table 7: Distribution of Papers by India in terms of Thin Films Applications during 2009-18

Sl. No.	Application Area	Total Papers (TP)			Share of Total Papers			TC	CPP
		2009-13	2013-18	2009-18	2009-13	2013-18	2009-18	2009-18	
1	Microelectronic Devices	12	21	33	0.24	0.27	0.26	147	4.45
2	Telecommunication Devices	4	9	13	0.08	0.12	0.10	64	4.92
3	Decorative Coatings	0	1	1	0.00	0.01	0.01	2	2.00
4	Optical Coating	137	254	391	2.74	3.30	3.08	3731	9.54
5	Protective Coatings	19	8	27	0.38	0.10	0.21	450	16.67
6	Batteries	21	53	74	0.42	0.69	0.58	934	12.62
7	Solar Cells	250	796	1046	5.01	10.35	8.25	10410	9.95
8	Sensors	350	567	917	7.01	7.37	7.23	11389	12.42
9	Catalysis	72	106	178	1.44	1.38	1.40	2597	14.59
		4992	7689	12681					

Profile of Top 20 Most Productive Indian Organizations

Four Hundred Twenty Four (424) organizations contributed to India's output in thin films research during 2009-18. Of these, 136 organizations contributed 1-10 papers each, 69 organizations 11-20 papers each, 96 organizations 21-50 papers each, 63 organizations 51-100 papers each, 23 organizations 101-200 papers each and 9 organizations 201-300 papers each, 7 organizations 301-500 papers each and 2 organizations 584-729 papers each.

The productivity of top 20 productive organizations from India in the subject varied from 182 to 729 publications, and they accounted for 51.29% (6509) national publication share and 61.05% (67579) national citation share during the period. The scientometric profile of these 20 organizations is presented in Table 8.

- Nine organizations registered publications output above the group average of 325.2: Shivaji University, Kolhapur (729 papers), Indian Institute of Science, Bangalore (584 papers), Inter-University Accelerator Centre, New Delhi (432 papers), UGC-DAE Consortium for Scientific Research, Indore (411 papers), Bhabha Atomic Research Centre, Mumbai (399 papers), Indian Institute of Technology, New Delhi (389 papers), University of Delhi (381 papers), Indian Institute of Technology, Bombay (358 papers) and National Physical Laboratory, New Delhi (374 papers);
- Six organizations registered impact above the group average citations per publication of 10.30 and relative citation index of 1.2: Shivaji University, Kolhapur (21.22 and 2.43), SASTRA University (11.28 and 1.29), University of Delhi (10.71 and 1.23), Jadavpur University, Kolkata (10.69 and 1.22), Bhabha Atomic Research Centre, Mumbai (10.57 and 1.21), Indian Institute of Technology, Roorkee (10.43 and 1.20)during the period;

Table 8: Scientometric Profile of Top 20 Most Productive Organizationsin Thin Films Research by India during 2009-18

Sl. No.	Name of the Organization	TP	TC	CPP	HI	ICP	%ICP	RCI
1	Shivaji University, Kolhapur	729	15469	21.22	57	356	48.83	2.43
2	Indian Institute of Science, Bangalore	584	5234	8.96	32	121	20.72	1.03
3	Inter-University Accelerator Centre, New Delhi	432	3648	8.44	27	117	27.08	0.97
4	UGC-DAE Consortium for Scientific Research, Indore	411	3501	8.52	28	83	20.19	0.98
5	Bhabha Atomic Research Centre, Mumbai	399	4219	10.57	32	86	21.55	1.21
6	Indian Institute of Technology, New Delhi	389	3633	9.34	31	82	21.08	1.07
7	University of Delhi	381	4081	10.71	32	71	18.64	1.23
8	Indian Institute of Technology, Bombay	358	2634	7.36	26	91	25.42	0.84
9	National Physical Laboratory, New Delhi	347	3567	10.28	28	82	23.63	1.18
10	Indian Institute of Technology, Kanpur	290	2468	8.51	24	80	27.59	0.97
11	Indian Institute of Technology, Roorkee	267	2786	10.43	25	41	15.36	1.20
12	Indira Gandhi Centre for Atomic Energy, Kalpakkam	246	1634	6.64	20	47	19.11	0.76
13	Indian Institute of Technology, Kharagpur	237	2261	9.54	25	48	20.25	1.09
14	University of Hyderabad	232	1793	7.73	22	43	18.53	0.89
15	SavitribaiPhule Pune University	224	1810	8.08	21	62	27.68	0.93
16	Alagappa University	219	2259	10.32	25	80	36.53	1.18
17	Indian Institute of Technology, Madras	218	1602	7.35	20	54	24.77	0.84
18	Indian Institute of Technology, Guwahati	182	1039	5.71	16	22	12.09	0.65
19	Jadavpur University, Kolkata	181	1934	10.69	23	26	14.36	1.22
20	SASTRA University	178	2007	11.28	25	34	19.10	1.29
	Total of 20 organizations	6504	67579	10.39	26.95	1626	25.00	1.19
	Total of India	12681	110693	8.73				
	Share of top 20 organizations in India total output	51.29	61.05					

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; HI=h-index; ICP=International Collaborative Papers; RCI=Relative Citation Index

Profile of Top 15 Most Productive Authors

Six Hundred Fifty Five (655) authors contributed to India's output in thin films research during 2009-18. Of these, 210 authors contributed 1-10 papers each, 178 authors 11-20 papers each, 135 authors 21-30 papers each, 97 authors 31-50 papers each, 33 authors 51-100 papers each and 10 authors 101-187 papers each. The productivity of top 150 most productive authors from India in the subject varied from 90 to 187 publications, and they accounted for 14.12% (1791) national publication share and 24.24% (26830) national citation share during the period. The scientometric profile of these 15 authors is presented in Table 9.

- Six authors registered publications output above the group average of 119.4: P.S. Patel (187 papers), C.D. Lokhande (182 papers), K. Asokan (138 papers), M.T omar (138 papers), V. Gupta (136 papers) and D.M. Phase (120 papers) during the period;

- Four authors registered impact above the group average of 14.98 citations per publication and relative citation index of 1.72: C.D. Lokhande (33.92 and 3.89), K.Y. Rajpure (25.89 and 2.97), P.S. Patel (22.52 and 2.58) and V. Gupta (16.76 and 1.92) during the period;

Table 9: Scientometric Profile of Top 15 Most Productive Authors in Thin Films Research by India during 2009-18

Sl. No.	Name of the author	Affiliation of the author	TP	TC	CPP	HI	ICP	%ICP	RCI
1	P.S.Patel	Shivaji University, Kolhapur	187	4211	22.52	37	129	68.98	2.58
2	C.D. Lokhande	Shivaji University, Kolhapur	182	6173	33.92	42	100	54.95	3.89
3	K. Asokan	Inter-University Accelerator Centre, New Delhi	138	903	6.54	15	38	27.54	0.75
4	M. Tomar	University of Delhi, Miranda House, Delhi	138	1331	9.64	21	15	10.87	1.10
5	V.Gupta	University of Delhi	136	2279	16.76	27	19	13.97	1.92
6	D.M.Phase	University of Kerala, Thiruvanathapuram	120	896	7.47	18	15	12.50	0.86
7	V. Ganesan	UGC-DAE Consortium for Scientific Research, Indore	114	1464	12.84	22	9	7.89	1.47
8	R.J. Choudhary	UGC-DAE Consortium for Scientific Research, Indore	110	829	7.54	17	22	20.00	0.86
9	C. Sanjeeviraja	Alagappa University	103	1239	12.03	18	23	22.33	1.38
10	T. Mahalingam	Alagappa University	100	981	9.81	18	67	67.00	1.12
11	D.K. Avasthi	Inter-University Accelerator Centre, New Delhi	97	1109	11.43	21	31	31.96	1.31
12	K.Y. Rajpure	Shivaji University, Kolhapur	97	2511	25.89	30	28	28.87	2.97
13	D. Kanjilal	Inter-University Accelerator Centre, New Delhi	92	767	8.34	16	24	26.09	0.95
14	D. Kaur	Indian Institute of Technology, Roorkee	90	1119	12.43	20	5	5.56	1.42
15	P.N. Bhosaale	Shivaji University, Kolhapur	87	1018	11.70	20	43	49.43	1.34
		Total of 15 authors	1791	26830	14.98	22.8	568	31.71	1.72
		Total of India	12681	110693	8.73				
		Share of 15 authors in India's total	14.12	24.24					

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; HI=h-index; ICP=International Collaborative Papers; RCI=Relative Citation Index

Medium of Research Communication

Of the total publications output by India in thin films research, 81.38% (10320) appeared in journals, 16.24% (2059) in conference proceedings, 1.40% (177) in book series, 0.73% (99) in books, etc. Four Hundred Twenty Four (424) journals reported India's research in thin films during 2009-18, of which 264 journals contributed 1-10 papers each, 66 journals 11-20 papers each, 50 journals 21-50 papers each, 23 journals 51-100 papers each, 16 journals 101-200 papers each, 3 journals 201-400 papers each and 2 journals 401-525 papers each**.**

The top 15 most productive journals accounted for 123 to 527 papers, accounting for 33.51% share (3462 papers) of total publicationoutput in journals during 2009-18. The 5-year publication productivity in journals increased from 30.99% to 35.11% between 2009-13 and 2014-18. The top most productive journal (with 527 papers) was *Journal of Materials Science Materials in Electronics*, followed by *Journal of Alloys and Compounds* (427 papers), *Thin Solid Films* (343 papers), *Applied Surface Science* (291papers), etc. during 2009-18 (Table 10).

Table 10: Top 15 Most Productive Journals in Thin Films Research by India during 2009-18

Sl. No.	Name of the Journal	Number of Papers		
		2009-13	2014-18	2009-18
1	Journal of Materials Science Materials in Electronics	83	444	527
2	Journal of Alloys and Compounds	193	234	427
3	Thin Solid Films	156	187	343
4	Applied Surface Science	187	154	341
5	Journal of Applied Physics	154	137	291
6	Materials Science in Semiconductor	49	144	193
7	RSC Advances	0	190	190
8	Materials Chemistry & Physics	83	82	165
9	Applied Physics Letters	83	72	155
10	Materials Letters	56	97	153
11	Applied Physics A. Materials Science and Processing	46	103	149
12	Sensor and Actuators B. Chemical	67	79	146
13	Materials Research	0	130	130
14	Ceramics International	23	106	129
15	Materials Research Bulletin	68	55	123
	Total of 15 journals	1248	2214	3462
	Total output by India in journals	4027	6305	10332
	Share of top 15 journals in Indian journal output	30.99	35.11	33.51

Highly Cited Papers

Of the 12681 papers published by India in thin films research during 2009-18, the country share of highly cited papers has been small, just 4.12 percent (52 papers) of its national output.All such papers that received 100 and 100+ citations since their publication have been defined for this study as highly cited papers.

- Fifty-two papers received 102 to 492 citations per paper since their publication, accumulated 7598 citations, and averaged 146.12 citations per paper.
- A total of 262 authors from 102 organizations spread across 9 collaborating countries contributed to these 52 highly cited papers.
- Of the 52 highly cited papers, 47 received 102-195 citations each, 2 received 221-224 citations each, 2 papers received 327-336 citations each and 1 paper each received 492 citations.
- Of the top collaborating partner counties, South Korea accounted for the highest number of highly cited papers (12) , followed by USA (8 papers), Germany (5 papers), Japan (3 papers), Singapore (2 papers), France, Netherlands , Sweden and Saudi Arabia (1 paper each);
- Of the top 35 Indian organizations participatingin highly cited papers, Shivaji University, Kolhapur contributed 19 papers, followed by Bhabha Atomic Research Centre, Mumbai and Indian Institute of Science, Bangalore (3 papers each), Alagappa University, Karaikudi, CSMCRI-Bhavnagar,

Dayalbagh Educational Institute, Agra, Indian Institute of Technology, Bombay and National Physical Laboratory, New Delhi (2 papers each) and rest of the organizations 1 paper each.

- Of the 52 highly cited papers, 22 were non-collaborative papers and 30 as collaborative papers (including 3 as national collaborative and 27 as international collaborative).
- Of the 52 highly cited papers, 43 appeared as articles and 9 as reviews.

The 52 highly cited papers appeared across 32 journals, with 4 papers each in *ACS Applied Materials & Interfaces* and *Electrochimica Acta*, 3 papers each in *Applied Surface Science, Journal of Membrane Science* and *Solar Energy Materials & Solar Cells*, 2 papers each in *Current Applied Physics, Desalination, International Journal of Hydrogen Energy, Journal of Alloys & Compounds, Journal of Power Sources, Materials Chemistry & Physics, Solar Energy* and *Sensors & Actuators B. Chemical* and the rest as 1 paper each in 19 other journals.

SUMMARY AND CONCLUSION

This paper provides a quantitative and qualitative description of thin films research in India vis-à-vis the world. The publications data for the study was sourced from Scopus database covering 10-year period 2009-18. During the period, the global output in the subject was 148374 publications, and it registered 2.20% growth during the period. During the same period, India contributed 12681 publications, registered 11.04% growth (five times the world growth), registered average productivity of 126.81 publications per year, and averaged citation impact of 8.73 citations per paper (CPP) in the subject.

India is the 5th top ranking country in world on publications quantity with 8.53% global publication share. China topped the list of top 10 productive countries in the world in thin films research. China (19.61%), the USA (17.71%), South Korea (9.57%), and Japan (9.37%) are ahead of India in world ranking. Except for China, India collaborated in thin films research with all top ranking countries and thereby contributed 23.47% share of its national output as international collaborative papers. India's collaboration was the strongest with South Korea (10.54% share), followed by the USA, Japan, and 7 more countries. Materials science has been the most sought after broader-area of research pursuit in thin films research in the country (64.51% publications share) compared to other broader areas like physics, chemistry, engineering, and energy. Amorphous thin films is the most popular sub-area of research in the subject, followed by research in other sub-areas like nano-crystalline thin films, polycrystalline thin films, epitaxial thin films and single crystals thin films during 2009-18.

Top research organizations that provided leadership to the country in thin films research include Shivaji University, Kolhapur,; Indian Institute of Science, Bangalore; Inter-University Accelerator Centre, New Delhi; UGC-DAE Consortium for Scientific Research, Indore; Bhabha Atomic Research Centre, Mumbai; Indian Institute of Technology, New Delhi; University of Delhi; Indian Institute of Technology, Bombay; and National Physical Laboratory, New Delhi. Research publications that India contributed to thin films research were published across 424 journals. The top 15 most productive journals in the subject that account for 33.51% share of total journal articles include: Journal of Materials

Science Materials in Electronics (527 papers), followed by Journal of Alloys and Compounds (427 papers), Thin Solid Films (343 papers),etc. India contributed but a very small share of its national output as highly cited papers (4.12%, 52 papers). These highly cited papers received 100 to 492 citations and averaged 146.12 citations impact per paper. A total of 262 authors from 102 organizations spread across 9 collaborating countries had contributed to these 52 highly cited papers. These 52 highly cited papers appeared across 32 journals including *ACS Applied Materials & Interfaces* and *Electrochimica Acta* (4papers each), *Applied Surface Science, Journal of Membrane Science* and *Solar Energy Materials & Solar Cells (*3 papers each), etc.

Given the fact that a total of 424 organizations from research and higher education sectors are currently engaged in thin films research in the country, it can be concluded India has indeed established a strong research base in thin films research in the country. India has been strong in registering a faster growth of 11%, five times the world growth in the subject. However, its global performance measured in terms of research quantity has been significantly below leader countries like China, the USA, and Japan. In terms of research quality, its performance (as seen from measures like 8.73 citations per paper, 4.12% share as highly cited papers) has not been very encouraging. Recognizing the potential role of thin films research in commercial and defence applications, there is a need for intervention in terms of policy support and funding to encourage and catalyze thin films research in the country. India needs to invest more in R&D, collaborate more with leader countries in the subject including China, and involve more trained manpower in this area to achieve its national objectives in the subject.

REFERENCES

1. Thin Solid Films International Journal on the Science and Technology of Condensed Matter Films. Available athttps://www.journals.elsevier.com/thin-solid-films(Accessed on 12 Feb 2019).
2. Thin films. Available at https://en.wikipedia.org/wiki/Thin_film(Accessed on 21 Feb 2019).
3. Chopra Kasturi, Thin film device applications (Springer; New York), 1983.
4. Patil, S B, Thin films research in India: A scientometric analysis of research output during 2000-15, *International Journal of Information Dissemination and Technology*, 2008, 8(1), 14-17.
5. Guo Ying, Huang Lu and Porter Alan L, The research profiling method applied to nano enhanced, thin film solar cells.*R&D Management*, March 2010, 40(2), 195-208.Available at https://doi.org/10.1111/j.1467-9310.2010.00600
6. Bhattacharya Sujit and Meyer Martin. Large firms and the science-technology interface Patents, patent citations, and scientific output of multinational corporations in thin films. *Scientometrics,* 2003, 58(2), 265–279.
7. Bhattacharya Sujit, Kretschmer Hildrun and Meyer Martin, Characterizing intellectual spaces between science and technology. *Scientometrics,* 2003, 58(2), 369-390.

❖❖❖